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ABSTRACT

Presented in this document is a full-year, two-semester course in geology for high school students. Composed of 5 units and 20 chapters, the course emphasizes the practical aspects of geology with special attention to the relationship between geoscience processes and the environment and to the application of scientific and technical expertise to problems facing society. The text is divided into two volumes, one for each semester, and supplementing each volume is a set of student activity sheets keyed directly to the various chapters of the text. Topics of the three units of volume 1 are: (1) what geology involves and why it is important; (2) the specific materials of which the earth is made and their special importance to people; and (3) how to visualize the earth by reading maps and understanding their uses. The two units of volume 2 deal respectively with: (1) the various processes involved in the structure and composition of the earth and their interrelationships; and (2) the forces that affect the earth's surface, for example, water, wind, and ice. In both volumes each chapter begins with a chapter outline, followed by a list of related activities, a set of "geo facts" (interesting trivia related to the topic under study), and a list of relevant terms. Concluding each chapter is a series of problems and questions related to the information provided in the main text. (AA)

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GEOLOGY IS

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Preliminary Edition

A Title IVc Innovative Project Developed at
O'Fallon Township High School
District #203
O'Fallon, Illinois

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Introduction to Students

What is GEOLOGY IS? It is a course in geology for high school students. The course is based upon the idea that the study of the earth is as important as any other natural or physical science in high school. The course emphasizes practical aspects of geology with a stress on environmental geology. It seeks to make an awareness of the relationships between the geoscience processes and the environment, and it encourages concern for the nation's well-being by applying expertise of scientific and technological nature to problems facing society.

The basic materials developed by the staff of GEOLOGY IS are a text and accompanying activity sheets specifically written for a secondary level geology course. The need for this text is thought to be basic because of the lack of geologic education in the secondary school. No secondary text now exists for a full year geology course; the only available materials are earth science texts with geology sections or college level geology textbooks.

What will you study? First, you will look at what geology involves and why it is important. Then, you will consider the specific materials of which the earth is made, and you will study how these materials are important to people. Next, you will study how to visualize the earth by reading maps and understanding their uses.

The next unit involves the study of the physical earth--the structure, the composition, and the forces that affect it. You will study such topics as structure of the earth, plate tectonics, earthquakes, volcanic activity, mountain building, plains and plateaus, and the interrelationships of these processes.

The final unit includes the study of the forces that affect the earth's surface--water, ice, and wind, for example. Again, the various geologic forces and agents are related to one another to show various relationships.

Within each chapter, following a chapter outline is a list of Related Activities that will be used for that chapter. Geo Facts follow the Related Activities in every chapter. They are simply trivia concerning the topic of the chapter that you may find interesting. You will next notice a list of terms including Geologic Terms followed by Straight Terms. The Geologic Terms are titled differently in each chapter, and each title relates to some subject within the specific chapter. The Straight Terms are those words we feel should be understood by any high school student. Now, you might ask yourself, "Self, how do I find the definitions of these Straight Terms?" Try a dictionary (but not for the Geologic Terms). At the end of each chapter, you will find a series of problems and questions. Answers to them are sometimes not found "word for word" in the text. They are designed to make you take the information you read and apply some thinking (Oh, no!) of your own.

In a separate booklet, there are various activity sheets. These will guide you through laboratory activities or will deal with topographic maps and aerial photographs. For each activity, you are given description which includes the objective (purpose), materials (even including pencils!), and procedure. You are to answer the questions and occasionally provide conclusions.

GOOD LUCK!

UNIT CONTENTS

UNIT I

Introduction

Chapter 1 What Is Geology?

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?
What is geology?

Unit I: Introduction

CHAPTER 1: What Is Geology:

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    3. Geomorphology
    4. Paleontology
    5. Structural Geology
    6. Stratigraphy
    7. Engineering Geology
    8. Marine Geology
    9. Astrogeology
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    12. Geophysics
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    - 4. Consulting
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- VII. Why Do You, as a Non-geologist, Need a Basic Geology Education?

Related Activities

Vocabulary

Find and recognize the importance of earth materials in your environment.

Summarize the magazine article "Role of Geologists in Wise Use of Earth."

Summarize the magazine article "God Fought the Devil."

Recognize situations using the scientific method.

Use the scientific method and prove the law of original horizontality.

Problems and Questions.

General Geo Facts

One of the greatest earthquakes in the United States occurred in New Madrid, Missouri in 1811, about 240 kilometers (150 mi) from St. Louis.

In 50 million years, Los Angeles will be a suburb of San Francisco.

The tallest mountain in the world is the island of Hawaii.

Caves are found in every state of the United States except Delaware.

Mount Everest was once part of the ocean bottom.

If the age of the earth were compared to a 24 hour day, man would have appeared in the last few seconds.

About 98.5 percent of the earth's crust is made up of only eight elements (of a total of 92 naturally occurring elements).

The North American continent is drifting west at about 2.5 centimeters (1 in) per year.

Only a very small fraction of life is recorded in rocks as fossils.

Man obtains most of his necessities of life directly or indirectly from the earth's crust.

The American mineral use of the past 30 years exceeds the total mineral consumption of all people of the world throughout history.

We may presently be in an interglacial stage, with readvancement of glaciers a possibility.

Three-fourths of all fresh water in the world is in the form of glacial ice.

There are about one million detectable earthquakes per year throughout the world.

If present glaciers would melt, sea level would rise, and coastal cities (such as New York) would be flooded; the Gulf of Mexico would extend up to southern Illinois.

The diameter of the earth is about 12,880 kilometers (8,000 mi), but the deepest mines are only about 3.2 kilometers (2 mi) deep; the deepest drill holes are only about 8 kilometers (5 mi) deep.

Missouri has about four thousand caves.

Chapter 1: Word List

Geo Terms

Catastrophism
Environmental geology
Geologist
Geologic hazard
Geology
Geomorphology
Hypothesis
Law of original horizontality
Law of superposition
Mineralogy
Neptunist theory
Oceanography
Paleontology
Petrology
Scientific method
Stratigraphy
Seismologist
Stratigraphy
Theory
Uniformitarianism

Straight Terms

Affluent
Anhydrous
Catastrophic
Cumulative
Environment
Evolution
Fauna
Finite
Flora
Incandescent
Martyr
Mythology
Revolution
Subsidence
Variable

UNIT I: INTRODUCTION

Chapter 1: What Is Geology?

SEE ACTIVITY 1.1

SEE ACTIVITY 1.2

I. What is geology?

I. What is geology? You may be curious as you begin this course in geology, wondering about such questions as--what is geology? When did it begin? Will it be interesting? What use is geology to man? This beginning chapter attempts to introduce you to the course of geology and its significance to man. Geology is the basic science of the earth. The word "geology" in its Greek origin means "study of the earth." Geology is the science dealing with (1) the materials which comprise the earth; (2) the processes acting within the earth or upon its surface; and (3) the origin and history of the earth.

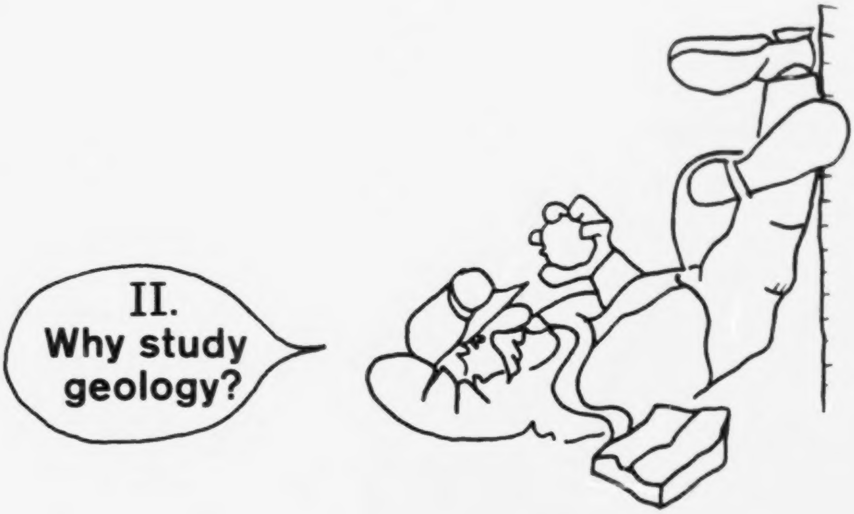
A. Fields of geology: Although geology is a relatively young science, it covers a very broad field, and many special fields have developed. The following gives some examples of these specialties:

1. Petrology: This is the study of rocks.
2. Mineralogy: This is the study of minerals.
3. Geomorphology: This is the study of the landforms of the earth.
4. Paleontology: This is the study of the past forms of life as seen in fossils.

   5. Structural geology: This is the part of geology which deals with earth's geologic structures and the forces and processes which cause them.
   6. Stratigraphy: This is that part of historical geology dealing with those earth events interpreted from the evidence found in sedimentary rocks.
   7. Engineering geology: This study combines the geologic specialties with engineering principles to interpret the interaction between the physical surface materials and construction activities and projects.
   8. Marine geology: This is the part of geology that deals with ocean basins and floors.
   9. Environmental geology: This is a study of problems associated with pollution: urban development, and geologic hazards.
   10. Astrogeology: This study applies the principles of geology to matter and gases away from the earth.
   11. Seismology: This is a study of earthquakes through the interpretation of seismic waves.
   12. Geochemistry: This is a study of the nature and distribution of chemical elements in earth materials.
   13. Geophysics: This is a study of heat flow patterns, seismic vibrations, and magnetic, electric, and gravitational fields.

B. What is studied in geology? Throughout the year, various aspects of the earth will be examined. They include the following:

   1. Earth materials: The origin of the earth is first considered. Then the scope is narrowed down to the minerals and rocks found on earth. Mineral resources and their impact on our lives are studied.
   2. Observing the earth: Various types of maps and map interpretation are introduced. They are important in studying geology.
   3. Internal processes: The structure of the earth and various processes that occur inside the earth are studied. These processes include plate tectonics, earthquakes, volcanoes, and mountain building.
   4. External processes: These will include processes that occur on or near the surface of the earth such as weathering, glaciation, wind action, and wave action.
   5. Summary: A glimpse is given of careers in geology. In addition, a summary is made of environmental concerns in geology that were scanned throughout the chapters.



II. The fact that we live on the earth justifies studying it. The more we know about our planet, especially in the area of environment and resources, the better we can understand, use, and value it.

A. Mineral resources: Mineral resources are quantities of materials found in the earth that have value to man. They are very important in our daily lives. In a matter of minutes, each of us could make a list of many items in our lives that would be absent if we were lacking a particular mineral resource. The following include a few examples.

1. Coal: The quality of coal as an energy source makes it invaluable as a resource. Fortunately, we still have a large supply of coal as yet to be mined.
2. Crude oil and natural gas: These are valuable as energy sources, and they are also used to manufacture innumerable products, including such unlikely items as soda straws. Unfortunately, our supplies of oil and gas are limited.
3. Sand and gravel: While it seems that we should have endless supplies of sand and gravel, in reality, we only have resources adequate for ten to 60 years. They are used primarily as construction materials. Quarried and crushed stone can be used in their place, but the process is more expensive and time consuming. This means, friends, that the consumer pays more.
4. Precious metals and gems: These include, among others, platinum, silver, and gold. They are probably the most effectively recycled resources simply because they are so rare that necessity has forced people to recycle them.

B. Environmental problems: Another area of geology that is of vital importance to people is the area of environmental problems. There are many geologic hazards resulting from people's presence and sometimes interference in the natural pattern of things. Environmental geology concerns itself with geologic application to these problems. The following include a few examples of some disasters that can occur.

1. Earthquakes: China and India can probably boast the highest earthquake death figures. The worst earthquake occurred in Shensi, China, when about 830,000 people lost their lives. During the summer of 1976, there were several earthquakes around the world. Again in China particularly, an intense earthquake occurred with rather severe aftershocks. Although the Chinese have been somewhat successful recently in predicting earthquakes, in this case there were no forewarnings, and several hundred thousand people were killed. Within a few weeks of the initial quake, another intense earthquake occurred in China. A few days later, a quake occurred in the Philippines. During an earthquake, where do you think the safest place might be?
2. Volcanoes: In terms of highest death toll, the 1883 explosion of Krakatoa, between Sumatra and Java, was the worst in history, claiming 36,000 lives. During the month of August, 1976, a volcano in the French West Indies was predicted to erupt violently. Authorities ordered the evacuation of 70,000 people. In late August, the volcanic eruption finally occurred. On what do you think these predictions may have been based?
3. Landslides: The most serious landslide in terms of death toll occurred in Kansou, China, in 1920, when 180,000 people died. When vegetation has been removed from the land, perhaps for lumbering, mining, or housing developments, landslides may occur. Examples of landslides resulting from housing developments have occurred from the East Coast to the West. What do you think might trigger these landslides?
4. A recent event: The first three environmental problems discussed were large disasters that made national newspaper headlines. There are also problems that are smaller in scope but nevertheless devastating to those involved. Can you recall a recent event or incident at the local, state, or national level involving the disruption in the environment caused by some geologic hazard? Was there any advanced warning? Could it have been prevented? How?

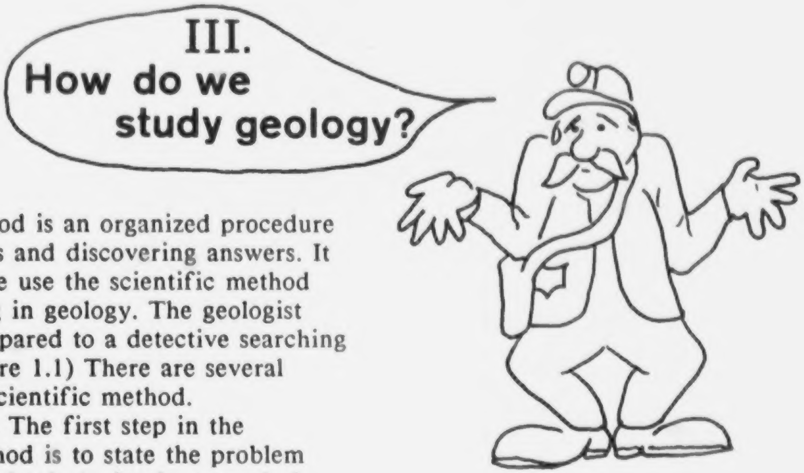
C. Research: One of the main themes of many geologists' research deals with origins. These origins can include the origin of the earth, the origin of various types of minerals and rocks, the origin of mountains, the origin of oceans, and the origin of rivers. In an age when energy, minerals, and water resources are at a premium and are presenting a problem, researchers are at work trying to find adequate solutions, not only in pressures generated by increasing population and urbanization, wise land usage and waste disposal become critical. Dwindling supplies of certain resources and changing societal needs challenge researchers to find alternate energy sources.

5

Much research is now directed toward predicting the occurrence os natural events which may or may not result in disasters. Through such predictions, scientists may never hope to control or prevent these natural occurrences, but with sufficient warning, loss of life and injury may be held to a minimum.

Research is being conducted into the cause of and ways to minimize the effects of man-made disasters. Providing new ways of disposing of radioactive waste, reduction of erosion caused by man's encroachment upon nature, and devising new conservation and cultivation techniques are only a few of the many and varied answers of geologic research.

SEE ACTIVITY 1.3



III. How do we study geology?

III. The scientific method is an organized procedure for asking questions and discovering answers. It is important that we use the scientific method for problem solving in geology. The geologist has often been compared to a detective searching for clues. (See Figure 1.1) There are several steps in using the scientific method.

A. State problem: The first step in the scientific method is to state the problem that is to be solved. A simple example is finding a rock and stating that the identity of the rock must be determined.

B. Make observations and collect data: Next, observations need to be made. This involves field experience, which is of extreme importance to the geologist. Data must be collected and arranged or classified in some manner. In considering the identity of the rock mentioned in A., all of the characteristics of the rock must be observed and organized in a useful manner.

C. Form hypothesis: From this collection of data, an attempt is made to arrive at some type of statement or explanation in answer to the problem. This is called the hypothesis. At this point, based on the information in B., a guess is made of the rock's name or identity.

D. Test hypothesis: The geologist cannot be sure that the hypothesis will always prove to be correct. As a result, testing must continue. It can be pointed out here that it is not always easy to test geologic hypotheses due to the difficulty of conducting laboratory experiments with such phenomena as volcanoes or geologic time. As a result, further observations are sometimes used in place of the experimentation stage. Also, some things are not directly observable, such as the earth's interior or past geologic events. For these, indirect observations are necessary. Again, back to the example of our rock: if possible, further tests are performed concerning the rock's identity.

E. Accept as theory: If the hypothesis continues to prove true, it sometimes is referred to as a theory. If it does not prove true, the beginning observations and data are reanalyzed, and a different hypothesis may be developed. In the sample situation, if all has gone well, the name of the rock has been proved. In a relatively simple situation such as this, step F. is not involved.

F. Accept as scientific law: Later, if the theory is continually proven to be true, it may become a scientific law. However, using "law" is often unwise because exceptions can sometimes be found.

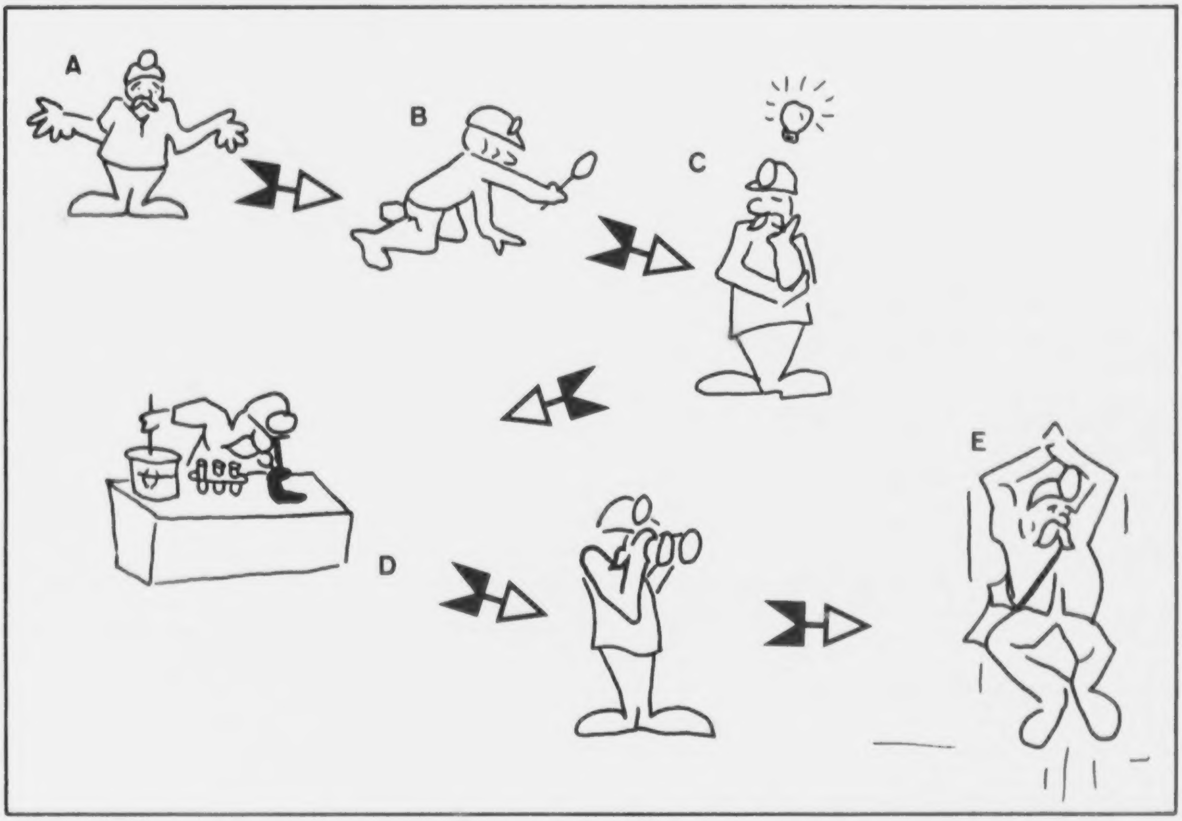


Figure 1.1. George Geologist follows each step of the scientific method to solve a problem.

For another example from start to finish, suppose we go to a roadcut to observe some rocks. We notice that all of the rocks appear to be lying in horizontal layers. From this information and from using logic, we conclude that the oldest layers occur on the bottom with progressively younger rock layers on top. We continue to test this hypothesis in the field and lab and find it to be consistently true. As a result, we refer to the hypothesis as a theory. We find this theory to be continually true, so eventually it is accepted as a law--the law of superposition. (See Figure 1.2)

Figure 1.2. A photograph of a roadcut. The oldest rocks are on the bottom, the youngest on top.

Sometimes, there may be apparent contradictions. For example, we may come to some layers of rock that have been completely turned over, and the law of superposition may not seem to work. Fine geologist that you are, you need to discover that the rocks have been overturned. Your conclusion would be that originally, the layers were deposited in an age sequence and were later altered. Thus, the law is still valid. Of course, this is an extremely simplified version of the processes involved.

SEE ACTIVITY 1.4

SEE ACTIVITY 1.5

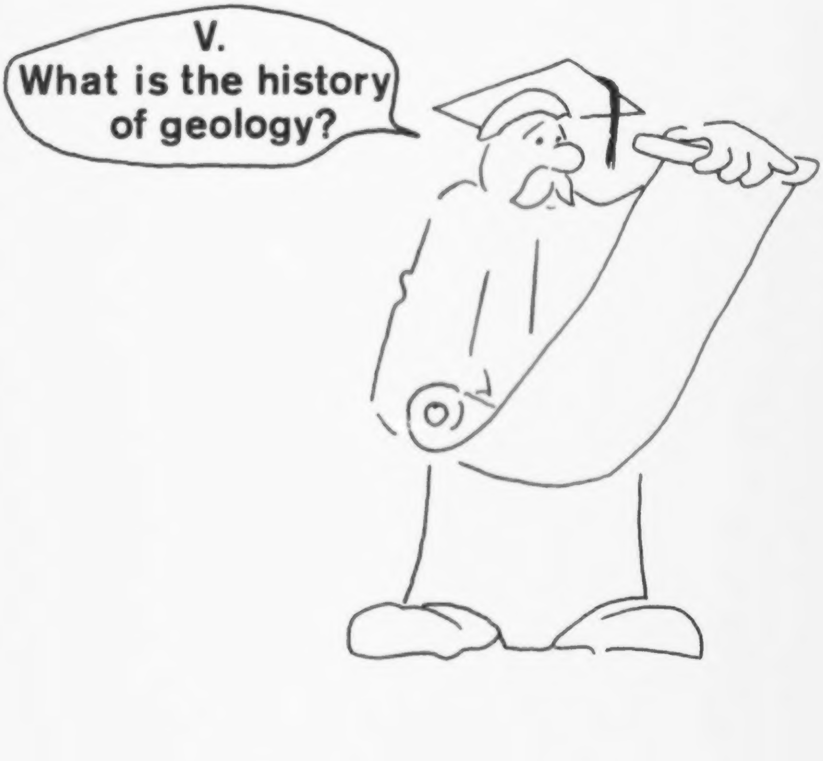
IV.
What is the relationship of geology to other areas of study?

IV. The study of geology blends the humanities, the social sciences, and the physical sciences into an integrated whole. To many, the study of geoscience as a natural science is more ideally suited for the liberal arts curriculum. The student is able to observe the earth as a container (and those forces acting to shape it) in the context of its natural setting as opposed to the laboratory setting. Through textbooks and textbook illustrations of those things one sees in nature, a student begins to understand how geologic processes interact, with a feeling of being a part of the process.

Yet, because of population intensity through urbanization, social and political aspects of science begin to pervade the geosciences. And, as data gathered in the other physical sciences are nearly always more exact, geoscience relates more to direct observation for explanations. To study geology descriptively, a student needs only to observe and discuss those events and processes which have and are continuing to form the earth's landscape. To study geology analytically a student must know some chemistry, biology, physics, and mathematics. Often, at the college level, students minor in one of these disciplines as they obtain a degree in geology. In a social and political sense, geoscience draws on data of man's evolution, his habitat, and his migration patterns to develop an appreciation for and a broader knowledge of the natural environment.

A. Physical sciences: Geology relates to the other sciences of chemistry, physics, and biology. For example, when a geologist picks up a rock, he tries to identify the kind of rock it is. From his chemistry training, the geologist would consider the different kinds of matter of which the rock is composed. He should also understand chemical reactions of rocks. Through physics, the geologist should be able to understand the effects of force, motion, or heat upon the rock. If plant or animal fossils were present in the rock, the biological aspects would be considered. The evolution of living things is a common concern of biology and geology, although the primary concern of geologists is the evolution of rocks and landscapes. Also, knowledge of biology is essential to understanding how living organisms can modify and/or control some geologic processes and vice versa. In other words, a geologist searches for understanding by viewing nature as a whole.

B. Non-sciences: There are also non-science subjects that can be related to geology. Gems for making jewelry are studied in art class. Oil, a topic of vital concern, is being studied from a geologic point of view (Where is it?) as well as an economic point of view (How much is it going to cost?). Name some ways to link geology to geography, history, economics, archeology, mathematics, P.E., home economics, shop, English, and art. Name one other subject that could relate to geology.


V.
What is the history of geology?

V. While geology as such is a relatively recent science, geology at a very basic level began thousands of years ago.

A. Early man: Throughout the ages, man has looked upon the face of the earth with wonder and sometimes, when threatened by earthquakes or erupting volcanoes, with terror. Early attempts to explain occurrences involved mythology and magic--early forms of religion. In addition, throughout time man has considered the earth as useful with regard to resources. When primitive man began to make tools from stones, he learned that some stones were better than others for making spear points, axes, knives, scrapers, and later, statues. What qualities might early man probably desire in making tools? At a very basic level, he was using geologic knowledge. Later, man learned that some types of rock were easy to quarry, and began to build permanent buildings of stone. In Greece, Egypt, Mexico, and Peru, men build beautiful buildings of stone using only stone tools. Why would stone buildings be better buildings than others, such as adobe or wood?

B. Later developments: It took man a long time to discover that superior tools could be made of metal. The only pure metals found near the earth's surface were gold, silver, copper, and very rarely, a little iron from meteorites. Gold and silver were much too soft and too rate for use in tools, but they could be used for ornaments. Copper may first have been used in the region near the Sinai Peninsula, between Africa and Asia. It was first used to make ornaments and religious implements, but eventually man learned that by mixing tin and copper, a hard metal (bronze) could be produced which was useful for making tools. Let us now look at some individuals and ideas which have had significant effects on geology.

1. Early Greeks and Romans: Some early Greeks and Romans influenced scientific thought for more than 2,000 years. They were hampered in several ways though. They were philosophers and not scientists. Their lives were conducted close to myth and folk knowledge, in a world of the unknown. Explanations of landforms were based more on imagination than on scientific analysis. For example, it was believed that rocks grew from seeds. There were several interesting Greeks and Romans, but we still consider two.

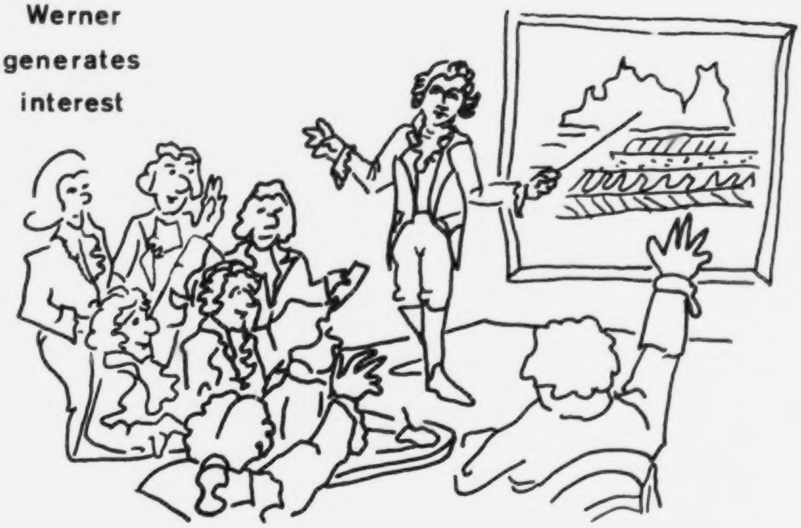
a) Aristotle: This Greek philosopher tried to explain natural phenomena using reason. His attempts to explain geologic occurrences sometimes came closer to the truth than many explanations that were to follow during the next few hundred years.

to Vesuvius

   b) Pliny the Elder: This Roman naturalist lived during the first century A.D. He was considered by the Romans to be a tower of wisdom. He wrote *Natural History* (37 volumes), of which five books were devoted to minerals. Unfortunately, he may be considered a martyr to scientific curiosity because he was reported to have died of asphyxiation when he approached too near Vesuvius, an active volcano in Italy, to observe the eruption in 79 A.D.

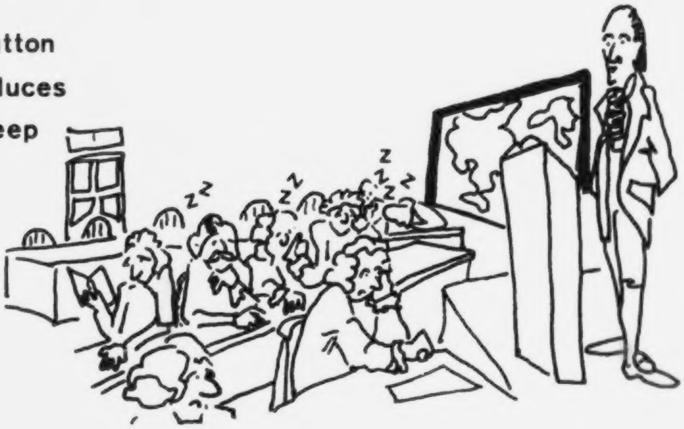
2. Fourteenth through the seventeenth centuries: Prior to seventeenth century, during the Dark Ages, there was not much understanding of geology or any other science because of conflicts with the Church. After this time, however, there was a revival of interest in science, and a knowledge of geology began to progress. The term "geology" was used in its present meaning at least as early as 1605.
   a) Leonardo da Vinci: Because of the new intellectual climate during the fifteenth century, da Vinci touched on many aspects of geology, some of which had been forgotten. In addition, he calculated the time of the earth's development, and, at a time when fossils were considered freaks of nature, he recognized that they were the remains of plants and animals.
   b) Nicolaus Steno: During the seventeenth century, he gave the first outline of a scientific history of the earth based upon observations and reasoning. He proposed the laws of superposition and original horizontality. These laws are extremely important in interpreting information from sedimentary rock layers. The law of superposition states that in rock layers, the oldest rocks are on the bottom with progressively younger rocks on top. The law of original horizontality states that sedimentary rocks are first deposited in horizontal layers.
   c) Francois Placet: In 1666, a French scholar, Francois Placet, suggested that the matching coastlines of eastern South America and western Africa proved the continents were separated during the Great Biblical Flood.
3. Eighteenth century: Modern geology began to develop in the eighteenth century. This occurred partly as a result of the need for practical knowledge of rocks and minerals in the mining districts of northwestern Europe and partly as a result of the accumulation and building of scientific knowledge.
   a) Abraham Werner: Born and raised in a mining district in Germany, Werner, from the time he was a small boy, was fascinated with the minerals and rocks found nearby. This interest continued for the rest of his life, and in addition, he became interested in other phases of geology. He developed the now discredited "neptunist" theory. This theory stated that all of the rocks of the earth's crust were formed in or near the water. As a fascinating teacher, he expressed many ideas about the earth's structure that were later found to be incorrect. However, he did contribute to the science of geology, and he published the first great textbook of mineralogy.

Werner generates interest



b) James Hutton: This Scotsman is regarded as the father of geology. He developed the theory of uniformitarianism which states the idea that all past changes on the earth's surface are the results of the same processes, however slow, that are occurring today. The theory is commonly expressed as "the present is the key to the past." Thing of an example of this. Because the theory of uniformitarianism covered infinitely long periods of geologic time and because changes on the earth's surface are slow and constant, many people rejected the theory because of conflict with religious teachings of the time. Unfortunately, Hutton was rather boring, and uniformitarianism did not find favor until the effective writing of Charles Lyell in *Principles of Geology*, in 1830.

Hutton induces sleep



4. Nineteenth century: Further developments were made in the nineteenth century.
    a) G. L. Cuvier: In opposition to the theory of uniformitarianism was the theory of catastrophism proposed by G. L. Carver, in 1812. He taught that at various times in the past, violent or catastrophic events occurred creating landforms and destroying life. Think of a natural event which could be considered catastrophic. Even though his theory was generally discredited, Cuvier did some important studies of fossils and is considered the founder of paleontology.
    b) William ("Strata") Smith: The orderly sequence of fossils, from simple to complex, in rocks was first recognized by William ("Strata") Smith in England, and by Cuvier in France. This made possible the study of layered rocks and the development of geologic maps. It also reinforced the law of superposition.
    c) Louis Agassiz: In 1840, Louis Agassiz established glacial geology on a firm basis by exploring the evidence of an ancient glacial lake in North Dakota, Minnesota, and Canada which was later named for him.
    d) James Hall: Around 1850, James Hall (American) attempted to show the relationship between rock types in New York State and Europe. However, his ideas were not seriously considered until about 60 years later when the theory of continental drift was developed.
    e) Charles Lyell: It was Charles Lyell who actually popularized the concept that an understanding of present processes will help us in making inferences of geologic history (concept of uniformitarianism).
    f) James Dana: In 1873, Dana gave the name "geosynclinal" (now geosyncline) to a subsiding trough structure.
    g) Clarence Dutton: In 1889, Clarence Dutton proposed the theory of isostasy (equal standing).
    h) William Morris Davis: In 1889, W. M. Davis described the erosional cycle in the life of a river.

C. Modern Developments: During the twentieth century, much progress has been made in the field of geology. The general theory of plate tectonics has dominated the thinking of the present century. Plate tectonics is a study encompassing the breaking of the lithosphere into plates or sections, plotting their relative motion in time, and revealing the activity which occurs when these plates interact. Developing from the earlier hypothesis of continental drift and aided by later discoveries of slow, steady separation of the earth's crust at under-sea ridges, resulting in fractures and upwelling lava (known as sea-floor spreading), plate tectonics has evolved. The lithosphere is broken into six major plates and numerous minor plates, including ocean basins as well as continents on the plates, which move on a layer of the mantle called the asthenosphere. Plate movement is attributed to convective currents generated by heat in the earth's mantle. Where these convective currents ascend to the surface of the earth, plates are pushed apart (North American and European plates). Where convection currents descend into the mantle, plates collide or slide past each other. The hypothesis of plate tectonics now gives us alternative explanations for the origin of mountains, causes of volcanoes and earthquakes, and reasons for other geologic events.

1. Modern names in geology: The following men have taken the field of geology into one of the most exciting adventures yet, that of plate tectonics.
    a) Alfred Wegener: In 1915, Alfred Wegener proposed the theory of continental drift which stated that the present continents were, at one time, one large landmass.

b) Harold Jeffreys: This Cambridge geophysicist was one of the critics most responsible for bringing Wegener's hypothesis of continental drift into disrepute. He showed that the tidal force proposed by Wegener was insufficient to produce the horizontal motion necessary to move continents.

c) Rollin T. Chamberlin: As a professor at the University of Chicago, he is quoted as saying that Wegener's hypothesis in general "is of the foot-loose type, in that it takes considerable liberty with our globe, and is less bound by restrictions or tied down by awkward, ugly facts than most of its rival theories."

d) Arthur Holmes: Although he, too, rejected the Wegener model as to its motions, Holmes introduced an alternative model of mantle convection.

e) S. K. Runcorn: Professor Runcorn was an early pioneer in the field of polar wandering and paleomagnetic research.

f) J. Tuzo Wilson: Professor Wilson, a Canadian geologist and geophysicist, formulated a hypothesis of a transform fault to explain the transverse fracture zones that cut across the mid-oceanic ridge. Also, in 1963, he suggested a concept of "hot spots" formed over magma sources in the upper mantle whereby a chain of volcanic islands are produced as the oceanic plate moves away from a zone of fracture. The full cycle of an ocean basin opening and closing has been named the "Wilson Cycle".

2. Future Developments: We have only scratched the surface of "space-age" geology in the last half of the twentieth century. The space program is currently providing us with data about the moon and several of the planets. It is likely that much of this data will not be interpreted or analyzed until the twenty-first century. It may very well shed new light on the origin of our solar system and the history of our earth. A geologist has now been in space, and the sky is the limit to what we can learn.

VI.
What is a geologist?

VI. A geologist is one who studies the earth relative to its origin, history, structure, composition, and processes (acting within the earth and upon its surface). One might say a geologist *is* what a geologist *does*. Most geologist are listed under the two main divisions of geology, physical and historical, each with their own specialties. Some geologists prefer to describe themselves with titles such as: economic, environmental, marine, or petroleum geologist; geochemist; geophysicist; astrogeologist; or planetary geologist.

- A. Functions and tools: The main functions performed by geologists include field work, laboratory work, office work, teaching, and consulting, although their work is seldom limited to a single type of activity. Some jobs include locating mineral resources, giving warnings for natural disasters, and advising that buildings are constructed on firm foundations.
    1. Field work: Field work includes any work that needs to be done outdoors at the site of interest. In doing field work, geologists examine rocks, rock outcrops, and rock cores from drilling operations. They determine the distribution, thickness, directional trend, and slope of rock layers. Geologists examine soils, rocks, and minerals to locate mineral resources such as coal, aluminum, iron, or gas. They make studies to determine if underground rock layers will bear the weight of buildings, bridges, railroad beds, and other structures, or if they can support the water to be held above by dams. Similar studies are performed to determine the historical development of the earth. Recently, geologist have become deeply involved in problems of pollution and waste disposal and are working with planning groups concerned with these problems. Research is being performed of the oceans and lunar landscapes.
    2. Laboratory work: Although a lot of research is done in the field, some work is done in the laboratory. Specimens of minerals, rocks, and fossils can be examined for microscopic, chemical, and physical properties, for example.
    3. Office work: Office work may include gathering and interpreting data supplied by field geologists, well drilling, libraries, and other sources. They also evaluate information from topographic and geologic maps and aerial photographs. They can use computers to record and analyze field data. This

information is then used in writing reports, making geologic maps, and determining geologic conditions of areas beneath the earth's surface.

4. Equipment: Geologists use a variety of equipment and instruments in the field such as rock hammers, compasses, gravity meters (to measure variations in force of gravity from place to place), clinometers (to measure angles of slopes), pocket lenses (to magnify rocks), and transits or theodolites (to measure angles through the use of mounted telescopes). Although not available to all geologists, some instruments, equipment, and tools of research include: (1) seismometer (to measure ground waves); (2) seismograph (to record ground waves); (3) infrared aerial photography (using the infrared, or long wave, portions of the electromagnetic spectrum which can be converted by special instruments and film into a visual image, a process called remote sensing); (4) seismic prospecting geophones (transforms seismic echoes or reflections into a seismic section to be translated into a picture of the strata beneath the surface); (5) mass spectrometer (to study positive particles of elements); (6) polarized microscopes (mineral identification using optical properties); (7) gravimeter (measures minute differences in gravity); (8) airborne magnetometers (to detect variations in earth's magnetic field and identify sedimentary rock layers); and (9) such exploration advances as the Glomer Challenger, a special ship designed for a deep-sea drilling project (Joint Oceanographic Institutions for Deep Earth Sampling).

B. Employment opportunities: There are various opportunities available, either through governmental agencies or private sectors.

1. Education: Many geologists are employed as teachers, primarily at the college level. Why do you think this is?
2. Industry: Most industrial geologists do research for petroleum or mining companies.
3. State and federal agencies: State geological surveys and the United States Geological Survey (USGS) employ many geologists in research capacities.
4. Consulting: Geologists doing consultant work frequently do so in addition to holding a position in one of the other three areas just mentioned. They work in an advisory capacity for various companies or government agencies.

C. Education and career outlook: Students seeking professional careers as geologists should acquire an advanced degree. The completion in college of a four-year undergraduate program in geology is generally considered an introduction to the field. It provides the background upon which the geologist's specialized training in graduate school is based. Undergraduate students usually devote one-third of their time to geology courses, one-third to mathematics and related sciences, and the remainder to general academic subjects. Employment opportunities for geologists with advanced degrees are expected to be favorable in the future. Many positions for professional geologists should be available each year because of the expected growth in the field and to replace positions caused by turnover or retirement. The outlook for geologists with a Bachelor of Science degree is only fair.

VII.
Why do you, as a non-geologist, need a a basic geology education?

VII. The science of geology is becoming increasingly more important to man as demands rise for more mineral resources and less environmental hazards. The public has opportunities to make decisions in voting for representatives in government and in advocating environmental concerns. Two issues relating to geology presently being examined nationally, statewide, and locally concern the construction of dams and the control of mine subsidence. Do you feel you are prepared at this point to make wise decisions concerning such issues? Why or why not? What do you think it would require to make wise decisions? In order for the general public to become aware of the problems and to be involved in the possible solutions, they must be informed. The most logical place to provide information is through the schools. From this course in geology, factual information and concepts will be presented, but the most important emphasis will be on geology's significance to man. We will deal with ways to apply geology to benefit mankind.

Chapter 1: Problems and Questions

1. Give one (1) example of how each of the following areas might relate to your own life: earth materials, observing the earth, internal processes, and external processes.
2. Name two (2) problems you can see in man's future in relationship to each of the following topics:
   minerals, geologic hazards, and land use.
3. Give two (2) examples of geological processes that would be difficult to study in a laboratory situation, and explain why.
4. How might you adapt to the following geologic hazards:
   earthquake, volcano, and landslide.
5. List and explain one (1) way that geology might relate to the following sciences, and tell how those sciences would be useful to the geologist: chemistry, physics, and biology.
6. Choose a science other than geology, and tell why you think it was necessary for the basic principles in this science to be well understood before geology could develop many of its ideas and concepts.
7. a. Explain Uniformitarianism and Catastrophism.
   b. Name two (2) examples of processes that show Uniformitarianism.
   c. Name two (2) examples of processes that might demonstrate Catastrophism.
   d. In your opinion, which Theory best explains geologic events? Defend your answer.
8. List the steps of the scientific method, and describe an example of your own using the

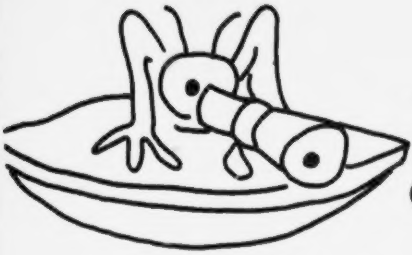
UNIT CONTENTS

UNIT II

Earth Materials

Chapter 2 Earth in Space
Chapter 3 Minerals
Chapter 4 Rocks
Chapter 5 Mineral Resources

Made in Hong Kong
Moon Rock #1



Unit II: Earth Materials

CHAPTER 2: Earth in Space

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    - 2. Big-bang Theory
    - 3. Oscillating Universe Theory
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        - (1) The Troposphere
        - (2) The Stratosphere
        - (3) The Mesosphere
        - (4) The Ionosphere
      - b) The Hydrosphere
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        a) Acids
        b) Bases
    2. Covalent Bonding
    3. Metallic Bonding

XI. Summary

Related Activities

Vocabulary

Identify physical and chemical changes.

Identify different types of matter.

Identify information obtained from the periodic table.

Balance chemical equations.

Problems and questions.

Earth in Space Geo Facts

Accurate maps of the stars were made long before accurate maps of the earth were made.

At 8 cents per kilowatt hour, New Yorkers alone would have to pay 400 million dollars a day to provide the light that comes to them free from the sun.

If a drop of water could be enlarged to the size of the whole earth, the atoms in it would only be the size of basketballs.

Astronomers have recently discovered that Saturn has three moons in one orbit.

Copernicus was the person to determine that the sun, not the earth, was the center of the solar system. However, he waited 13 years to publish his findings, because he feared a reprimand from the Church.

Our sun is located near the outer edge of the Milky Way and is only one of 100 billion stars that comprise the Milky Way.

Molecules are so small that it would take 100 million of them lined up side-by-side to make a row one inch long.

Chapter 2: Word List

Spaced Out Terms

Astronomy
Atmosphere
Atom
Atomic mass
Atomic number
Atomic theory
Balanced chemical equation
Big Bang Theory
Chemical bond
Chemical change
Chemical equation
Chemical formula
Compound
Core
Correlation
Cosmology
Covalent bonding
Electrical charge
Electron
Element
Encounter Theory
Family
Galaxy
Gas
Gravitation
Group
Hydrosphere

Ion
Ionic bonding
Isotope
Light year
Liquid
Lithosphere
Mantle
Mass
Matter
Metallic bonding
Mixture
Molecule
Neutron
Nucleus
Oscillating Units Theory
Period (chemical)
Periodic table
Physical change
Planet
Product
Proton
Protoplanet theory
Radioactive
Reactant
Satellite
Shell
Solar System
Solid
Star
Steady State theory
Sun
Universe
Volume

Straight Terms

Celestial
Chemistry
Condensation
Dense
Distortion
Expansion
Finite
Fireball
Infinite
Orbit
Original
Primeval
Radiate
Recede
Regenerate
Revolution
Rotation
Solar
Space
Spherical
Stable
Subatomic
Substance
Thermal
Tide

UNIT II: EARTH MATERIALS

Chapter 2: Earth in Space

I. Introduction: To find clues to the origin of the earth, one needs to scan the universe, bringing together all the pieces of information we can gather about the galaxies, the stars, the planets, and the natural satellites. As we focus in on the earth we need to bring to our study all the relative data that physics and chemistry have to explain the composition of our earth's materials.

II. The universe: Most scientists feel that we are witnessing today the aftermath of an event which may have occurred as many as 10 billion years ago. As we study the ways that the universe may have originated, we are faced with deciding which of the various theories are correct in explaining the existence of galaxies, single stars, planetary systems, natural satellites, and the chemical elements.

   A. Origin of the universe: It is possible that the universe (the largest known feature) may have its beginning in hydrogen (the simplest element). The universe includes all matter and all space. The science that deals with the celestial bodies is astronomy. Cosmology is the branch of astronomy that deals specifically with the origin, structure, and evolution of the universe. Of the various models hypothesized for the universe, most astronomers favor some kind of explosive beginning, although other models are proposed and accepted by a few.

      1. Steady state theory: The steady state model, at least in its original form, has fallen out of favor. It may, though, be the simplest to understand in that it states that the universe is not only the same everywhere but at all times. In this model of an expanding universe, galaxies spread out with new galaxies forming in spaces newly created (are you spaced out already?). New matter, freshly created hydrogen, for new galaxies is being created, out of nothing. This model depicts the universe as infinitely large and infinitely old, with no beginning and no end. A problem most scientists have with this model is that it violates the principle of conservation of matter and energy. Astronomer Fred Hoyle is credited with the design of this model. (See Figure 2.1)

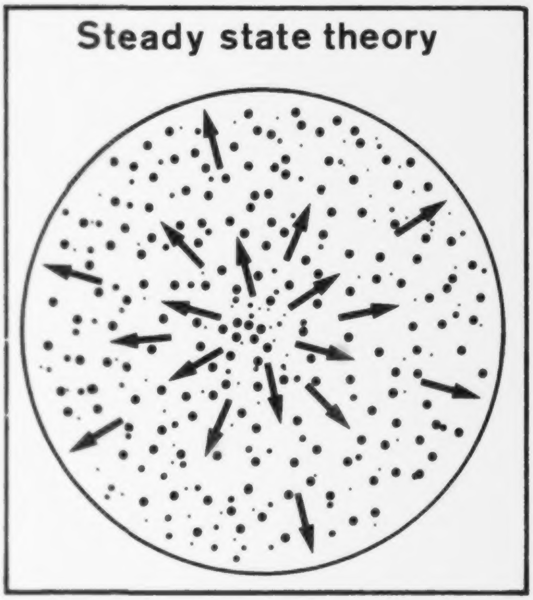


Figure 2.1. Illustrates the steady state theory. Arrows indicate the direction of expansion of the universe as it moves outward, to be lost. Newly created matter then replaces that which has been lost. The universe has always looked the same and always will.

2. Big-bang theory: This theory assumes that before a violent explosion and dispersal of material the matter of the universe was contained in a highly compressed, intensely hot state. This theory predicts a finite age (probably in excess of 10 billion years) with the universe continuing to expand indefinitely (that is a very long time), with distances between galaxies continuing to increase and with the space between the galaxies growing emptier. (See Figure 2.2)

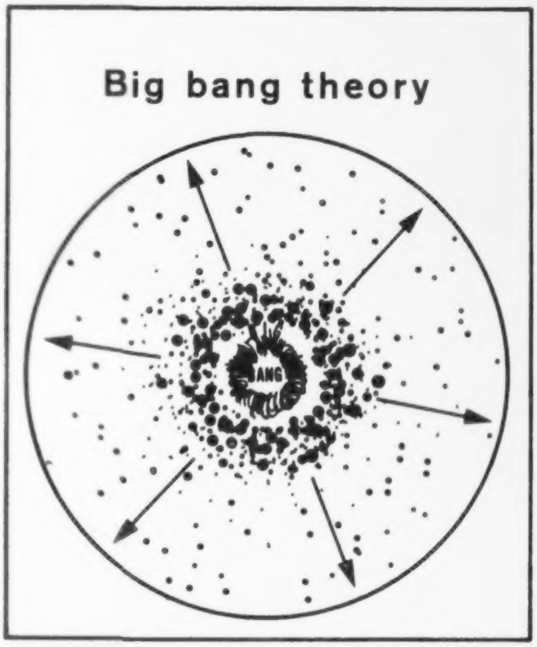


Figure 2.2. Illustrates the big bang theory. It suggests that perhaps all of the matter in the universe was once tightly packed in one unstable sphere that exploded.

3. Oscillating universe theory: This theory is a modification of the big-bang theory in that it suggests that gravitational attraction will bring expansion to a halt in time. In other words, it does not project an indefinitely expanding universe. Contraction will eventually bring the universe to its pre-primeval fireball state. At that time, another cataclysmic explosion will occur with the density of radiant energy again exceeding the density of matter. Matter will once again be dispersed through space, namely another big-bang cycle is in progress. (See Figure 2.3)

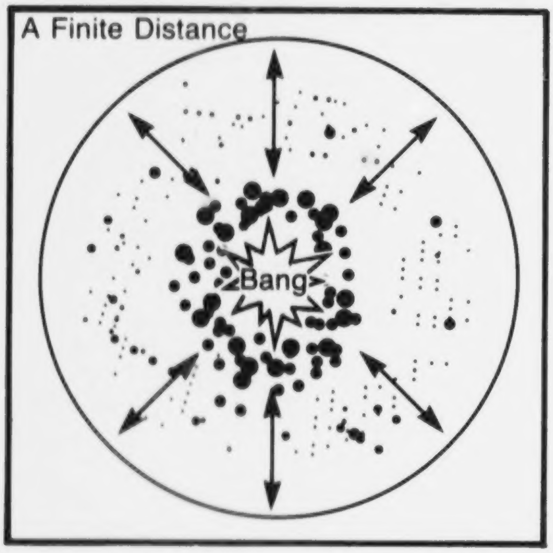


Figure 2.3. Oscillating Universe Theory

4. Summary: It is possible that positive proof of the origin of the universe may forever escape scientific minds. Most data seems to verify that we are in an expanding cycle, originating initially from some kind of cosmic explosion. Most scientists tend to agree on such a model, but there is disagreement about what is in store in the future for the universe. One of three events may be possible in such a model: (1) expansion may continue forever; (2) expansion may simply cease after a period of time with expansion and contraction fighting a stand-off; or (3) expansion may stop, contraction would cause the galaxies to collect back together, and regeneration could begin again with the universe oscillating indefinitely between expansion and contraction.

B. Characteristics of the universe: George Gamow, former professor of Theoretical Physics at George Washington University, indicated that in the first stages of expansion after the explosion density of radiant energy exceeded the density of matter, therefore matter could not aggregate (gather together). In subsequent stages, matter became gravitationally more important when density of radiation decreased with expansion. Gamow suggested that the original homogeneous gas now began to aggregate as clouds, or protogalaxies.

III. The galaxies: The galaxies consist of clusters, or islands, of individual stars. There are estimates of literally billions of galaxies in the universe.

A. Characteristics of the galaxies: As the gas cloud, or protogalaxy, aggregates, it begins to shrink due to the force of its own gravity. As the density increases, smaller pockets of gas, proto-stars, begin to appear. Most galaxies are either elliptical or spiral in shape, with elliptical galaxies probably being more numerous. Spiral galaxies have spiral arms radiating outward from a central core.

In 1929, Edwin Hubble introduced his law of recession of galaxies in an expanding model. Essentially, the law states that: (1) a galaxy's velocity of recession is proportional to its distance; and (2) the farther the galaxy is away, the faster it recedes.

If we assume that the average distance between galaxies in a cluster is at least a million light years and assuming also that there is a chance for galaxies to collide, collision of stars within the galaxies would be rare. Imagine two units of the same marching band, representing two galaxies with the members representing the stars within the galaxies, marching toward the center of the football field with motions at right angles to each other. With rare exception, the two units are able to pass through the other without a single collision.

B. The Milky Way galaxy: Our own Milky Way galaxy is a typical spiral galaxy with our sun located about two-fifths of the way in from the edge on one of the spiral arms. (See Figure 2.4)

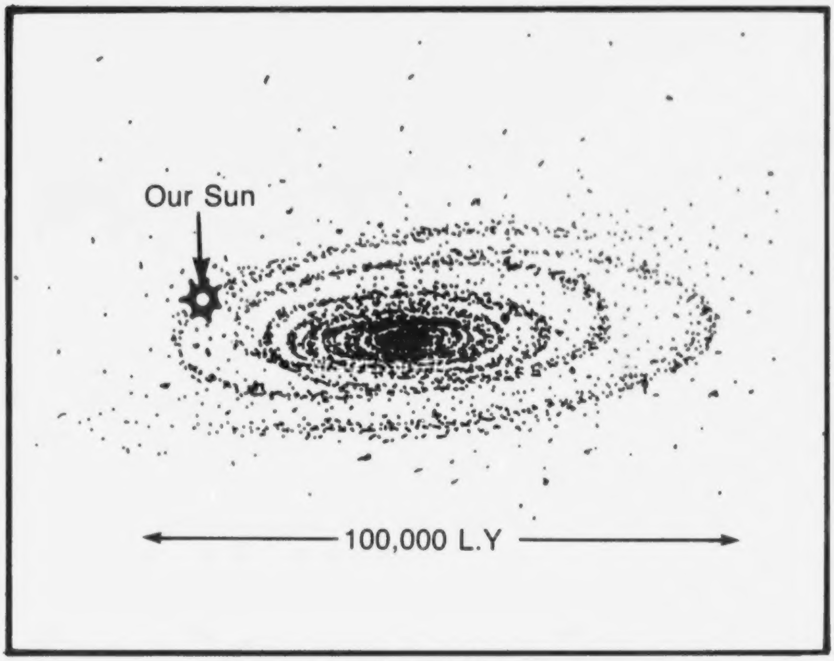


Figure 2.4. The Milky Way Galaxy

The Milky Way galaxy contains in excess of 100,000,000,000 stars and has a diameter of 100,000 light years (distance that light travels in a year's time). Travelling at 186,000 miles per second, light will travel nearly 6 trillion miles in one year.

The Milky Way galaxy rotates like a gigantic pinwheel with our sun completing one circuit in about 200 million years. The nearest visible galaxy to us (naked eye) is the Andromeda galaxy. Light seen on earth originating from Andromeda left that galaxy 2 million years ago. One has to wonder what changes the galaxy may have gone through that we don't know about. Is it still there?

As the proto-stars continue to aggregate (collecting the interstellar gas and dust), true stars finally develop, and the true-galaxy becomes a reality.

IV. The Stars: For centuries, man has been fascinated by the twinkling, diamond-like pinpoints of light in the night sky. A star is a heavenly body that gives off its own light. It must not be confused with planets which revolve around a star and merely reflect light from that star.

  A. Origin and Evolution of Stars: As a proto-star forms, its own gravity causes it to shrink. The gaseous matter accelerates toward the core and begins to heat. At some critical point, the heat effected by the collapsing gas turns the star into a luminous object, and eventually, nuclear reaction begins. This reaction known as thermonuclear fusion, is a process where hydrogen nuclei are fused into helium and energy.

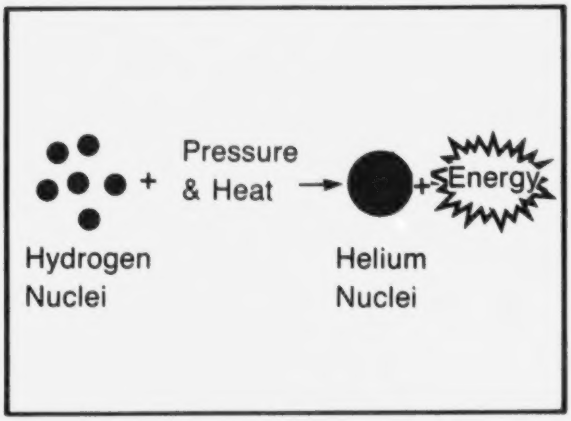


Figure 2.5. A closeup view of hydrogen in a star subjected to a great deal of heat and pressure, then turning into helium and releasing tremendous amounts of energy.

1. Star classification: Stars are classed on the basis of color and temperature. The hottest stars are classed O, and the coolest are classed M (O, B, A, F, G, K, and M). O and B stars are blue, A stars are blue to white, F stars are white, G stars are yellow, and K and M stars are red.

2. Life of a star: Ninety percent of all stars fall on the main sequence of the H-R diagram (Hertzsprung-Russell) once hydrogen fusion reaction begins. Mass of the star determines its position on the main sequence with blue giants at one end and the red dwarfs at the other. (See Figure 2.6)

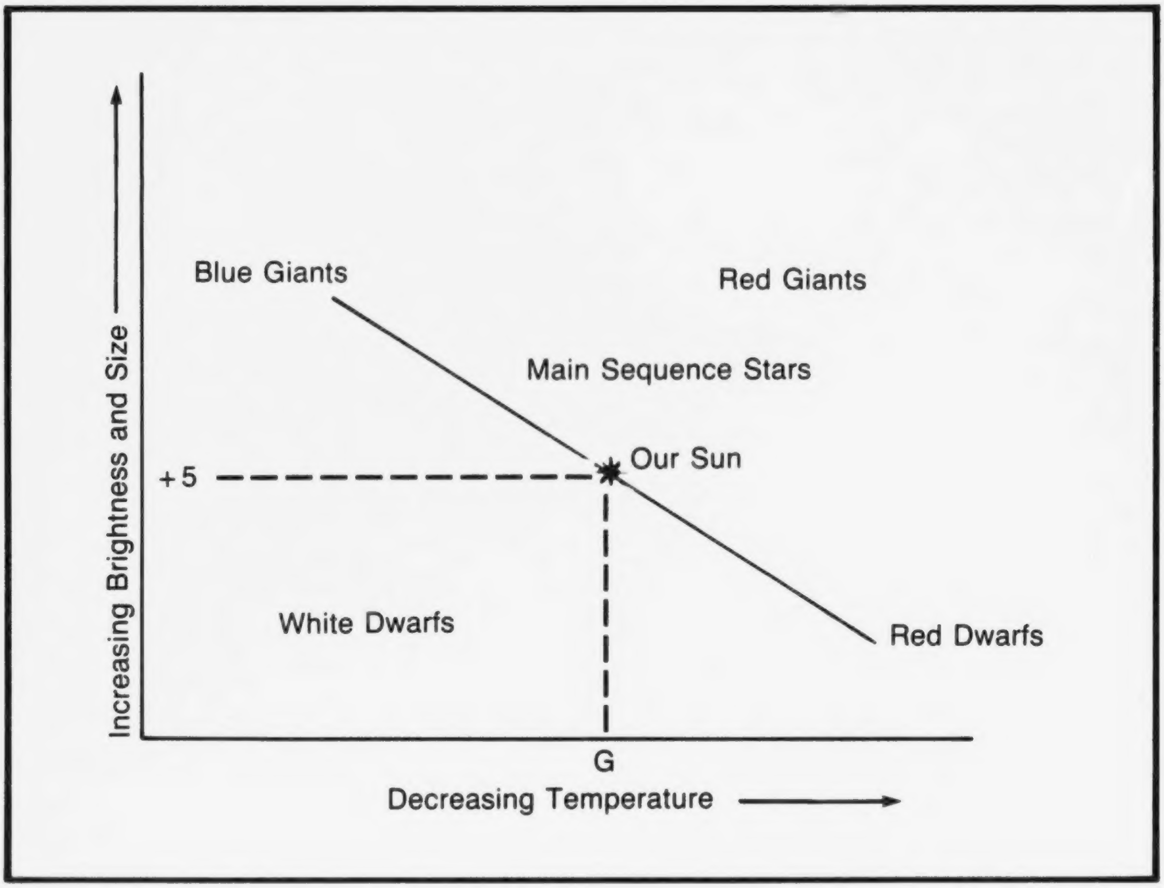


Figure 2.6. An adaptation of the Hertzsprung-Russell Diagram.

In a later stage of the star's life, helium which is produced in thermonuclear fusion moves toward the core of the star because of gravity. As collapse continues, the generated heat causes the outer shell of hydrogen to expand. Once the star has greatly expanded and its energy begins to escape as radiation, it becomes brightly luminous and is seen as a red giant. It now exits from the main sequence to begin a stage in its life where conversion of helium into carbon takes place. If the mass is the right amount, contraction of the carbon core may bring the red giant to the collapsed state of a white dwarf. Further collapse may bring the white dwarf to a stage where no radiation can escape the star, now a black dwarf. More massive stars may never pass through the white dwarf stage; their collapses may take them to a super-dense neutron star stage (pulsating signals from these gives us the name pulsars). Continued collapse may produce a star with such gravitational force that light is not able to escape from it, hence a black hole. Some massive stars explode before reaching the black hole stage. These expel energy in the form of radiant energy and expanding gas. It is estimated that these explosions liberate as much energy as our sun does in a hundred million years. A supernova is thus born. An example of a supernova is the Crab Nebula in the constellation Taurus (the bull).

B. Our sun as a star: Our sun is an average star, yellow in color (G), falling centrally on the H-R diagram (surface temperature of 11,000°F.), and approximately 5 billion years old. See Figure 2.7) Its life expectancy on the main sequence is expected to continue for another 5 billion years. Its mass is great enough to allow it to move into the red giant cycle, expanding as it does so as to consume both Mercury and Venus in the process. Earth will now be so close to the sun's outside shell as to become virtually uninhabitable. Our sun as a diameter over one hundred times greater than earth's diameter. Approximately two-thirds of all the elements found on earth have been identified on the sun. About 99 percent of the sun is hydrogen and helium, with hydrogen making up nearly three-fourths of the sun's mass.

V. Our planetary system: Our solar system is comprised of nine known planets, some 48 moons, and many smaller pieces of material. About 99.9 percent of the mass in the solar system is contained within the sun.

A. Origin of the solar system: As in the case of the origin of the universe, many theories have been proposed to account for the formation of our solar system. Only two will be discussed.

1. The encounter theory: This theory suggests that material may have been pulled from the sun by the tidal force generated by a passing star (a close encounter of a star kind, that is!). (See Figure 2.7)

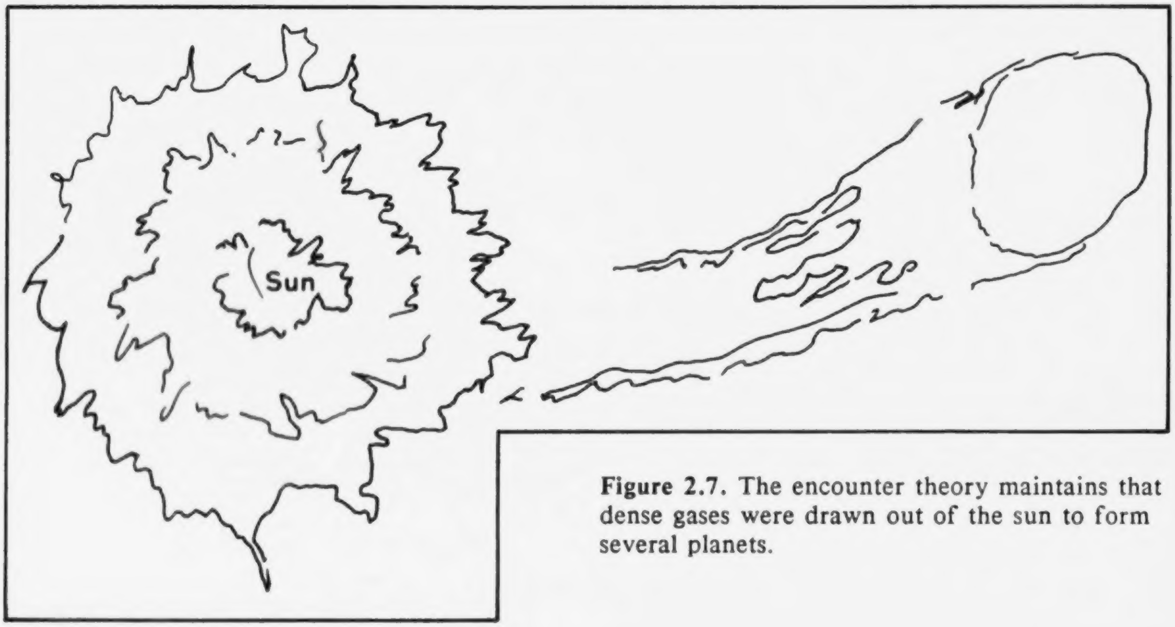
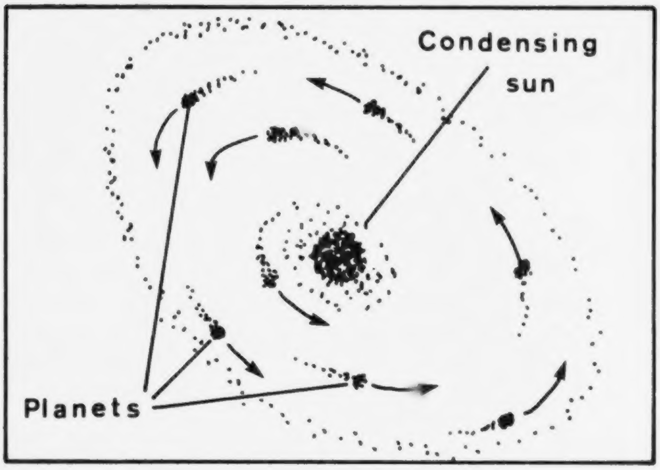


Figure 2.7. The encounter theory maintains that dense gases were drawn out of the sun to form several planets.

2. The protoplanet theory: This theory proposes that planets formed at the same time that stars formed, from the same gas cloud and under the same contracting conditions. While the larger centers are forming stars, the particles of dust and gas at the outer edge of the cloud are aggregating into planets. (See Figure 2.8)

Figure 2.8. The protoplanet theory of the origin of our solar system says it may have formed from a spinning disk of gas and dust as shown.



B. Characteristics of the solar system: Planetary systems may be possessed by a great number of stars in the universe. Suppose we consider the possibility of finding a planetary system (other than our sun's system) somewhere in the Milky Way galaxy. We have over 100,000,000 stars to investigate. If only one percent were predicted to have planets orbiting them, then there would be 1,000,000 planetary systems in the Milky Way galaxy. Now suppose that we were to look for a solar system similar to ours with a star comparable to our sun in size and temperature and with a planet comparable to earth in size, temperature, and distance from the parent star. Suppose only one percent of the 1,000,000 systems meet these criteria. Then there would be 10,000 systems similar to the earth-sun system. Now suppose we look for planets comparable to earth with these requirements: (1) an atmosphere composed chiefly of nitrogen (78%) and oxygen (21%); (2) a liquid ocean (not necessarily water) of some hydrogen-containing mixture; and (3) an adequate supply of carbon. If we assume that only .01 percent of the 10,000 systems meet these three prerequisites, then somewhere out there in the Milky Way galaxy there is another "earth" system, with a possibility of life as we know it. If we assume that there is an equal change of at least one in each galaxy, then there must be, conservatively speaking, nearly a billion "earth" systems somewhere in the universe.

1. Planets: The sun has nine known planets in revolution around it. (See Figure 2.9)

   The earth, at an average distance of 93,000,000 miles (1 A.U.), is the third planet outward from the sun. Only Mercury and Venus orbit the sun at a closer distance. Mercury, Venus, Mars, and earth (the terrestrial planets) are relatively small and dense; all are believed to be composed of rock and metallic material. Jupiter, Saturn, Uranus, and Neptune (the Jovian planets) are much larger and consist mostly of hydrogen and helium. Pluto is comparable to earth in size and probably, because of its great distance from the sun, has an icy composition.

   All of these planets orbit the sun in a counterclockwise direction if viewed from above the north pole of earth. These orbits form ellipses of low eccentricity (nearly circular) that lie in nearly the same plane.

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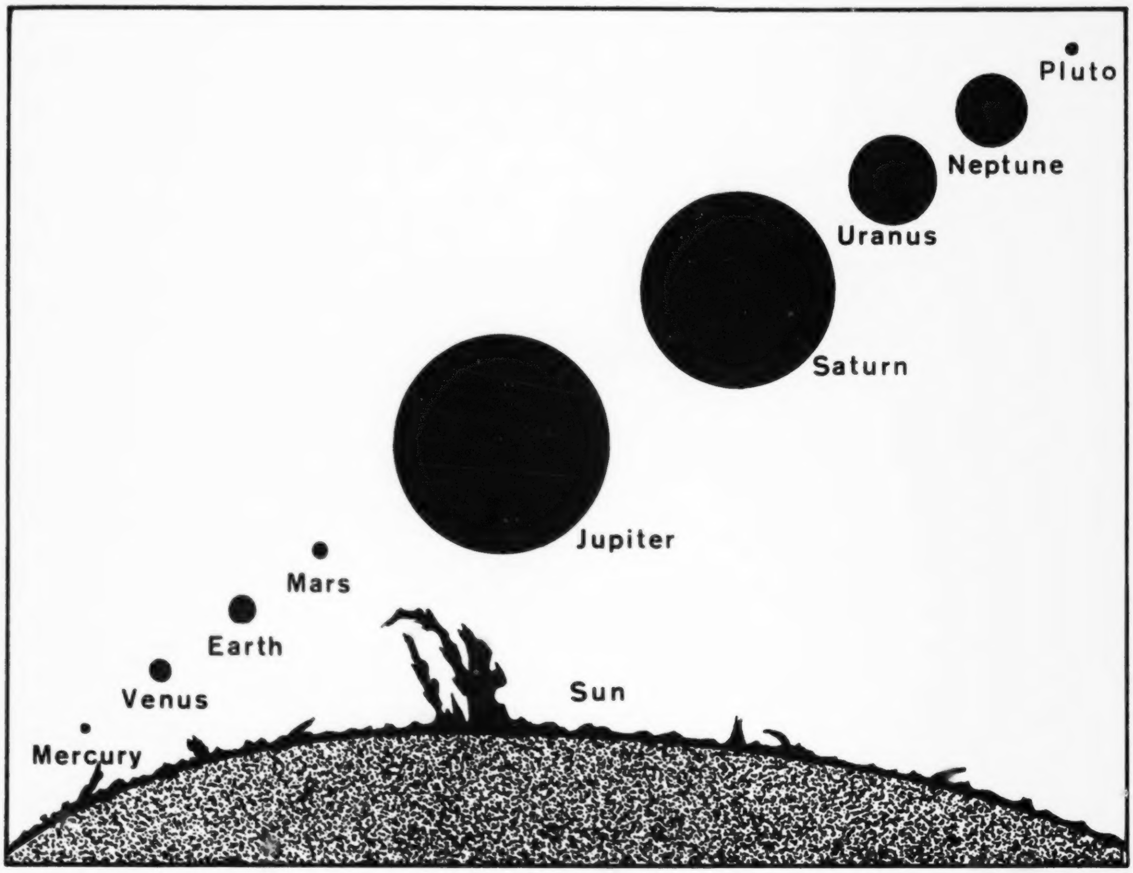

Figure 2.9. Shows the order of the planets from the sun. Also shows a comparison of the size of the planets and the sun. Note: Neptune is now farther away from the sun than Pluto.

a) Mercury: Mercury is the least massive and smallest planet. It completes three rotations (days) during two revolutional periods (years). On Mercury, the sun rises and sets in a period of 88 days. A heavily cratered surface, very much like our moon, dominates the landscape.

b) Venus: Venus appears third in brightness in our sky, after the sun and moon. Because of its inferior orbit (only three-quarters that of earth), it appears to move no further from the sun than an angle of 47° (about twice the maximum angular separation of Mercury from the sun). It, therefore, appears as an evening "star" after sundown in the western sky and as a morning "star" before sunrise in the eastern sky. Venus comes closer to earth than does Mars, the next closest planet. Like earth, Venus is believed to have an iron-rich core.

American satellite fly-bys and Soviet entry probes disclose features resembling lava deposits, mountains, volcanic peaks, and craters with some evidence of recent tectonic activity. The atmosphere is composed chiefly of carbon dioxide, resulting in a "greenhouse" condition (480°C. temperature) similar to that found on earth except at a much larger scale.

The period of rotation (day) is no longer than the period of revolution by 18 days. This causes a retrograde (reverse) direction of rotation similar to that found for Uranus.

c) Mars: Mars, the red planet, appears to have polar caps varying in area depending upon the season. The Mariner fly-bys did not substantiate the contention that these are like earth's ice caps but instead showed us a waterless and lifeless planet with volcanoes and craters and with a network of channels near the equator.

Mars is only about half as big as earth. The Martian day is slightly longer than our day. The tilt of its axis is slightly more than that of earth's. Seasons occur on Mars as they do on earth, but they last twice as long because mars takes twice as long to orbit the sun.

d) Jupiter: Jupiter is the largest and most massive of the planets. It appears as the fourth brightest object in the sky. Observationally, telescopes reveal alternating dark and light bands parallel to the equator. The most conspicuous of all Jupiter's markings is the Great Red Spot, an oval region which is possible a cyclonic (low pressure) weather disturbance. Jupiter is thought to have a liquid body (hydrogen), a solid outer core (metallic hydrogen), a solid inner core (iron-silicate), and a soupy atmosphere composed mainly of hydrogen and helium. Jupiter has not lost its original gases and resembles the sun more than it does the earth. With at least sixteen moons, Jupiter resembles a miniature solar system.

e) Saturn: Saturn is second in size to Jupiter and appears brighter than every star except Sirius (the dog star) and Canopus. The density of this planet is the lowest of all the planets, only .7 times that of water. Like Jupiter, Saturn radiates more heat than it absorbs from the sun. Saturn has an atmospheric chemistry and internal construction like that of Jupiter.

The most conspicuous characteristic of this planet is a circular ring system at its equator. It has not been determined if these rings are remnants of satellites which broke up gravitationally or whether forces kept satellites from forming.

f) Uranus: This planet is barely visible with the naked eye. It contains a rocky core, a shell of ice, and a thick layer of molecular hydrogen. Nine distinct rings have been found encircling Uranus. These rings are thinner and less colorful than those around Saturn. The equatorial plane of Uranus is inclined 98° to its orbital plane. What this means, essentially, is that the planet appears to be lying on its side with its north pole slightly below the plane (upside down?). Rotation, for this reason, is reverse of that for all the planets except Venus.

g) Neptune: Neptune was the first planet whose position was predicted before it was discovered (because of discrepancies found in the orbit of Uranus). Internally, Neptune and Uranus are similar. Neptune is currently farther from the sun than Pluto and will be until the 1990's. Its median distance is less than that of Pluto.

h) Pluto: Pluto was discovered in 1930. It has the most eccentric orbit of all the planets, and in the early 1980's, it moved inside the orbit of Neptune. In 1978, a moon was reported orbiting Pluto. Because of the 12 to 1 ratio of the masses of Pluto and Charon, it may be possible that they are a double planet.

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Future ?
What ?
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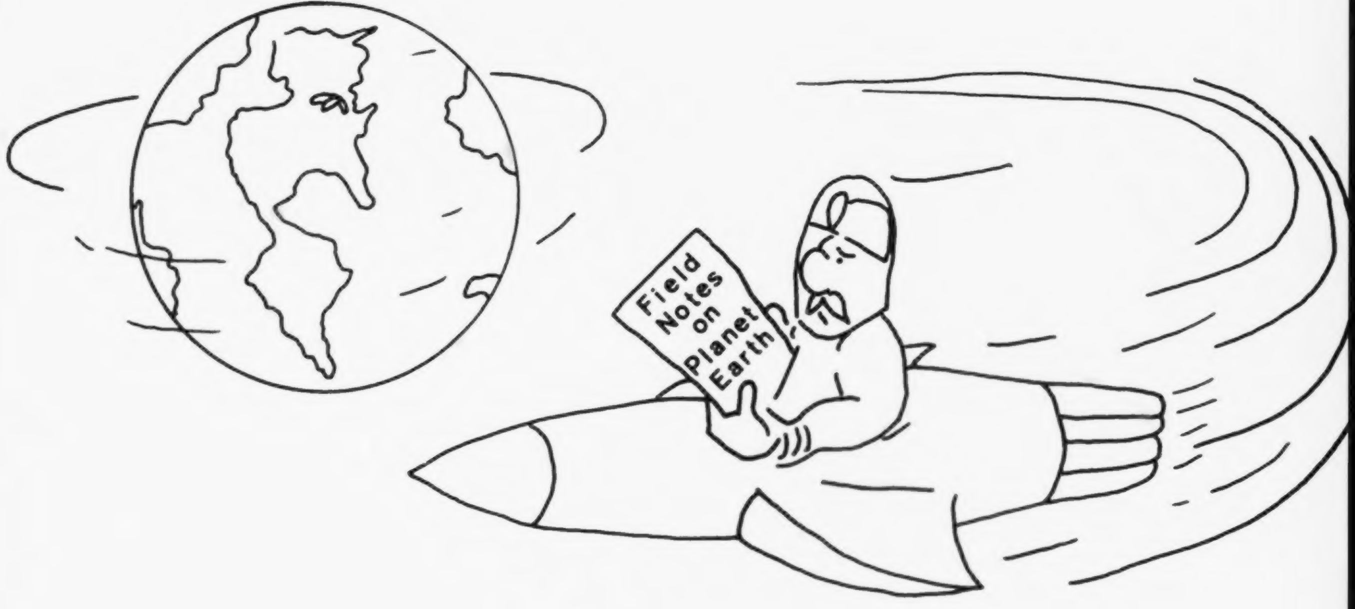
When?

2. Moons in our solar system: There are some 48 moons in our solar system that have been identified. Only Mercury and Venus have no known moons. These moons may have come into existence at the same time and under the same conditions as the planets. Most of the moons revolve around the planets with the sun counterclockwise direction at that which characterizes the revolution of the planets around the sun. A few of the moons of Jupiter and Saturn revolve in a clockwise direction, possibly because they might have been captured by the gravitational fields of the two planets after the initial formation of the planets and moons. Saturn has the greatest number of known moons.


Field Notes on Planet Earth

Atmospheres have been found to exist on a few of the moons. Our moon and moons smaller than our moon have lost most, or all, of their atmospheres because of weak gravitational forces. Our moon has a diameter about one-fourth that of earth and a mass of about one-eightieth that of earth. Some scientists refer to the earth-moon system as a double planet. The moon rotates in 27 1/3 days and revolves in 27 1/3 days. As a result of these identical periods, the moon presents the same "face" to earth.

The surface of the moon is marked with many craters and basins (maria or "seas"). Scientists disagree on the origin of these craters, but it is probable that both volcanic action and meteorite impact played a part in creating the moonscape. Rocks brought back from the moon have been found to be on the order of 4.6 billion years old and have compositions similar to rocks on earth.

C. Earth in the solar system: It has taken us some time to progress through the universe to earth, but we have finally arrived. Earth seems to have the most to offer of all the bodies we have studied, don't you think. Which other is so beautiful (or ugly), so just right in the amount and composition of the air to breathe and so blessed with all those things necessary to our everyday well-being (soil, water, minerals)? And how lovely those animals are on earth with the possible exception of the one across the table from you)! Aren't you glad you got dropped off here?

1. Earth's size and shape: The earth is nearly spherical (only slightly oblate due to rotational forces) with an equational diameter of nearly 8,000 miles. The earth's circumference is, therefore, slightly less than 25,000 miles. Mercury, Venus, Mars, and Pluto are smaller and less massive while Jupiter, Saturn, Uranus, and Neptune are larger and more massive than earth. In average density, earth ranks first.
2. Motions of the earth: Many of earth's motions are insignificant to the study of geology or are so slight as to be imperceptible. The two motions of consequences are rotation and revolution.
   a) Rotation: The most noticeable effect of rotation is the "rising" and "setting" of the sun. As the earth rotates full turn (360°) on its axis (an imaginary line connecting the geographic poles), a day of about 24 hours is completed.
   b) Revolution: The earth speeds around the sun at the rate of 66,000 miles per hour (you now have an answer for the Trivial Pursuit game!) at a distance varying from 91.5 to 94.5 million miles (average distance of 93 million miles or one astronomical unit). With the earth having its axis tilted 23 1/2° from the perpendicular to the revolutional orbit, the most noticeable effect of revolution is the changing of the seasons. (See Figure 2.10) The earth takes a year (365 1/4 days) to complete an orbit of the sun. In this time, both hemispheres are subjected to the direct rays of the sun equally. When the sun is directly above the earth's equator (March 21 and September 23) in the apparent exchange between hemispheres, earth is beginning its spring and fall seasons. When the sun shines farthest north and south of the equator directly (June 21 and December 21), earth is beginning its summer and winter seasons.
3. Composition of the earth: The planet has three major spheres: (1) the atmosphere (an envelope of gases surrounding the main body of the planet); (2) the hydrosphere (the total water realm); and (3) the lithosphere (in general, this refers to the entire solid earth realm).
   a) The atmosphere: In order for a body to retain a particular gas in its atmosphere, the molecules of that gas must not exceed speeds greater than one-sixth that of the speed of escape from the body. This is the reason that our moon has lost its atmosphere. Earth has lost most of its hydrogen and helium (if indeed they were ever present in abundance).

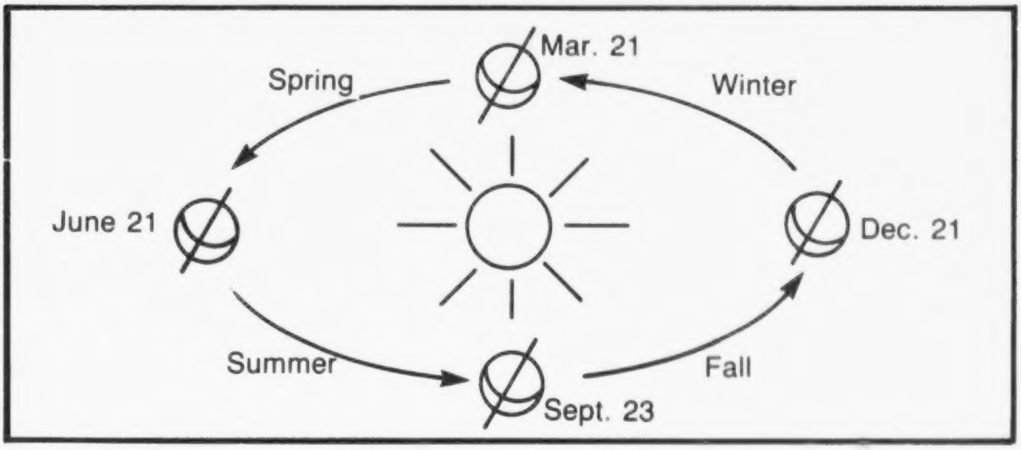

Mar. 21
Spring
Winter
June 21
Dec. 21
Summer
Fall
Sept. 23

Figure 2.10. Revolutions and Seasons (N. Hemisphere).

In the lower atmosphere (referred to as the homosphere nitrogen and oxygen comprise about 99% of the free atmosphere by volume. Argon, carbon dioxide, and very small amounts of helium, hydrogen, ozone and other gases make up the remaining 1 percent of the mixture of gases in the homosphere.

In the upper atmosphere (above 120 miles), the gases thin out to nearly vacuum conditions and tend to arrange in layers. This part of the atmosphere is referred to as the heterosphere. From the homosphere outward there is found oxygen, helium, and hydrogen in separate layers. (See Figure 2.11)

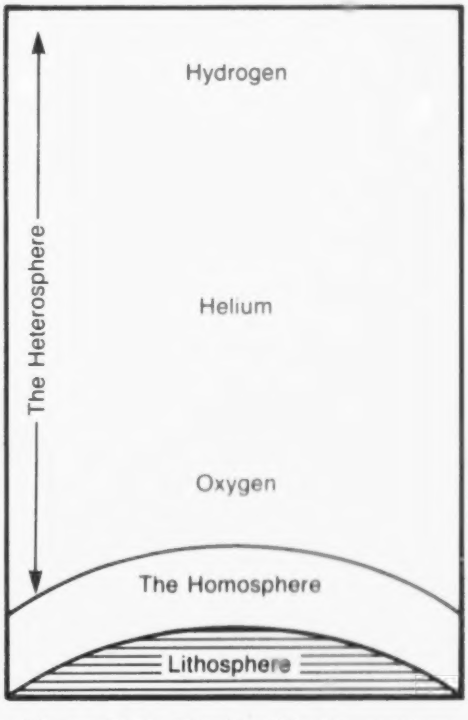

Hydrogen
The Heterosphere
Helium
Oxygen
The Homosphere
Lithosphere

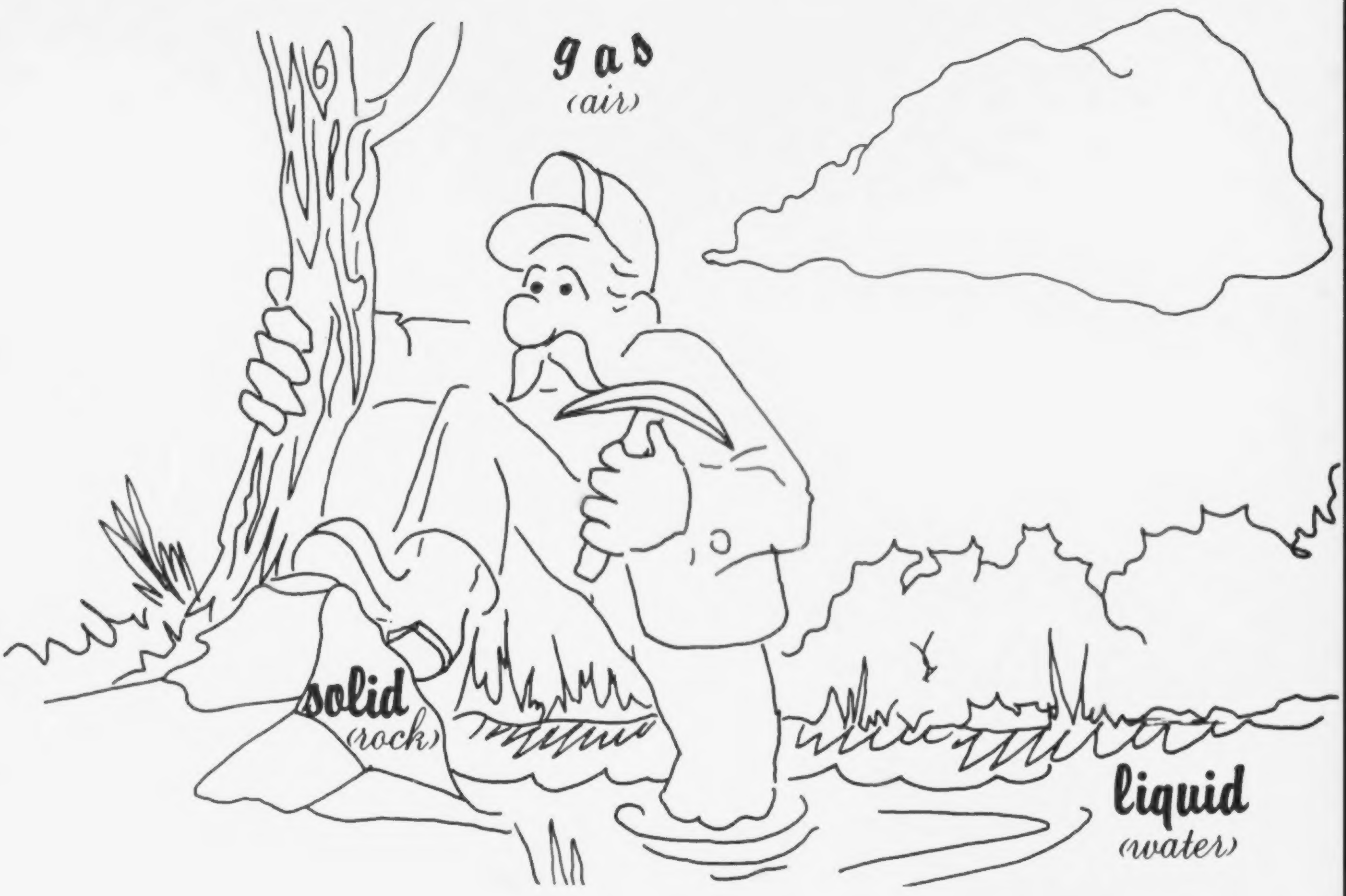
Figure 2.11. The Earth's Atmosphere

        - (1) The troposphere: The layer of the homosphere next to the earth's surface is called the troposphere. This layer varies in thickness from about 5 miles at the poles to 10 miles at the equator. This layer is sometimes referred to as the "weather" sphere. Temperatures decrease through the troposphere up to the tropopause (top of the troposphere).
        - (2) The stratosphere: The second layer of the homosphere is called the stratosphere. Very little weather (tops of some severe thunderstorms) occur in this level. It is generally clear and dry, and the winds blow horizontal to the earth's surface (a great place to fly, right?).
        - (3) The Mesosphere: Above the stratosphere and extending to the lower ionosphere is the layer called the mesophere. It is above this layer that the homosphere grades into the heterosphere.
        - (4) The ionosphere: In this layer, electrons have been stripped from the atoms leaving the atom positively charged. This process is called ionization. It is in this layer, near the magnetic north and south poles, that the auroras (northern and southern lights) originate.
    - b) The hydrosphere: The hydrosphere is the total water realm, including the oceans, water contained on the surface of the land, waters moving across the surface of the land, and ground water. Some scientists also include the water in the atmosphere (water vapor and clouds) and water in the frozen state (glaciers).

      The oceans occupy about three-quarters of the earth's surface and have a mean depth of 10,000 feet. About 97 percent of the free water on earth is found in the oceans. Water, as well as the atmosphere, may not have been present at the time of the formation of the earth. Gases given off during eruptions of volcanoes may have provided the necessary gases and water vapor to create an atmosphere (through the action of sunlight) and water (through the condensation process) for the oceans.
    - c) The lithosphere: Generally, this term is used for the entire solid earth realm. There are four distinct divisions of the lithosphere: (1) the crust; (2) the mantle, (3) the outer core; and (4) the inner core. (See Chapter 8 for an in-depth study of the lithosphere.) The earth's outer layer, the crust, comprised of hard, brittle rock, is also referred to as the lithosphere. Below this layer lies the asthenosphere (the upper layer of the mantle).
- 4. Summary: It is now time to begin our study of the earth's materials. Matter will be discussed with reference to only the three states of solid, liquid, and gas. Atomic structure, grouping of elements, and chemistry (for avid geology students) are units which precede the chapters on minerals and rocks.

VI. Matter: Matter is anything that takes up space and has mass (the amount of material in something). It has specific physical properties such as color, hardness, and mechanical strength. It has certain chemical properties enabling it to react when brought in contact with certain other substances.

- A. States of matter: A state is the form or physical condition of a material. There are three different physical states of matter: solid, liquid, and gas. Not all matter can be confined to one single category, for some matter can change from one state to another depending upon variations in temperature and pressure; the changes are also reversible. A familiar example is ice, water, and steam.



1. Solid: A solid has a definite rigid shape of its own and takes up a specific amount of space (volume), such as sa rock.
2. Liquid: This material takes up a definite amount of space (has a definite volume) but has no specific shape of its own. It conforms to the shape of its container. An example is water.
3. Gas: This material has no definite volume or shape of its own. The air you breathe is an example of a gas. Right now, your thoughts are running wild with curiosity, correct? Are your thoughts matter? Why or why not?

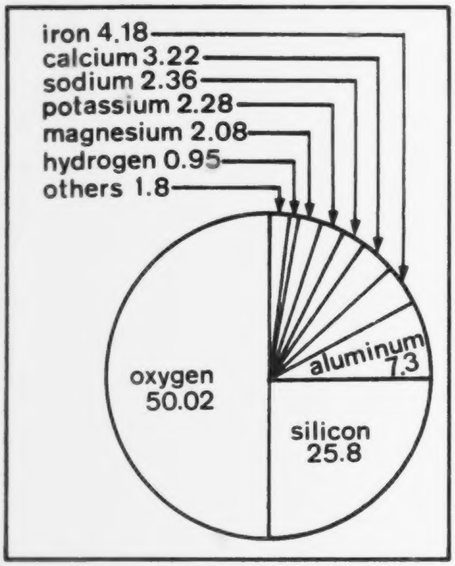
B. Changes in matter: Changes are going on around you and in you all of the time. There are two kinds of changes.
   1. Physical change: This is a change in the form, shape, or size of any substance, but no new substance is formed. If you crush a rock with a hammer, you create a pile of gravel. You simply change the size of the rock; no new substance is formed.
   2. Chemical change: A chemical change results if a substance breaks down or combines with another to form a new substance. The new substance has different properties from the original substance. When wood is burned, the wood is changed into gases and charcoal. These in no way resemble the original wood.

SEE ACTIVITY 2.1

C. Types of matter: Every kind of matter is different from every other kind of matter in one or more ways. Despite this, scientists have been able to classify matter into three main types.

1. Element: This is a simple substance that cannot be broken down into a simpler substance by ordinary chemical means. Each element is represented by one or two letters which are called chemical symbols. Some of the elements with which you are familiar include oxygen, iron, silver, and gold. (See Table 2.1) The most abundant elements include oxygen, silicon, iron, aluminum, calcium, potassium, magnesium, and hydrogen. (See Figure 2.12)

Figure 2.12. Illustrates the abundance of the elements in the earth, sea, and atmosphere.



2. Compound: When specific amounts of two or more elements join together by means of a chemical change, they are said to chemically combine. A compound is a substance that is made up of two or more elements that are chemically combined in definite proportions. It is not possible to see the individual elements, so it is impossible to tell if something is a compound simply by looking at it. Some familiar compounds include salt, sugar, and soap. (See Table 2.2)

Table 2.1. Some Useful Elements

Name	Symbol	Uses (alone or in compounds)
Aluminum*	Al	Kitchen pans, airplane parts
Antimony	Sb	Type metal, medicine
Argon	Ar	Electric light bulbs
Arsenic	As	Insect powders, small shot, knocking off old ladies
Barium*	Ba	Paint, paper coatings, signal flares
Bismuth	Bi	Medicine, alloys
Boron	B	Boric acid, borax
Bromine	Br	Poison gases, tear gas, ethyl gasoline, photographic film
Calcium*	Ca	Limestone, limewater, quicklime, mortar, bleaching powder
Carbon*	C	Coal, diamonds, pencils, ink
Chlorine*	Cl	Germ killer, bleaching compounds, table salt, making eyes sting at the swimming pool
Chromium	Cr	Rustproof plating, stainless steel
Copper*	Cu	Coins, electric wires, kitchen pans
Fluorine*	F	Insect powders, etching glass, preventing tooth decay
Gold*	Au	Jewelry, filling teeth, causing wars
Helium*	He	Inflating balloons, refrigerant, electric welding
Hydrogen*	H	Fuel, cutting and welding metal, making synthetic fats, making bombs
Iodine*	I	Germ killer, medicine, dumped in salt to prevent goiter
Iron*	Fe	Buildings, steel, magnets
Lead*	Pb	Paint, pipes, solder, shot, ethyl gasoline
Magnesium*	Mg	Airplane parts, signal flares, medicines
Manganese*	Mn	Dry cells, steel, black paint, glass
Mercury*	Hg	Thermometers, barometers, filling teeth
Neon	Ne	Advertising signs, orange-red tubular electrical discharge lamps (huh?)
Nickel*	Ni	Coins, plating other metals
Nitrogen*	N	Fertilizers, explosives, ammonia
Oxygen*	O	Breathing, burning, cutting and welding metal
Phosphorus*	P	Matches, rat poison
Platinum	Pt	Jewelry, chemical equipment
Potassium*	K	Gunpowder, fertilizers, soap
Radium	Ra	Medicine, luminous paint
Silicon*	Si	Glass, grinding stones
Silver*	Ag	Coins, jewelry, tableware, mirrors
Sodium*	Na	Table salt, baking soda, lye, soap
Sulfur*	S	Matches, gunpowder, fireworks, dyes
Tin*	Sn	Plating metals, solder, making alloys such as bronze and pewter
Titanium*	Ti	Steel, cutting tools, paint, smoke screens
Tungsten	W	Electric light filaments, tools
Uranium*	U	Atomic energy, atomic bomb
Zinc*	Zn	Dry cells, coating on galvanized iron

*You are responsible for knowing these elements and symbols because they are present in the most common minerals.

Table 2.2. Some Common Compounds

Common Name	Formula	Uses
Alcohol, wood	CH_3OH	Solvent, antifreeze, do not drink this one!
Alcohol, grain	C_2H_5OH	Solvent, antifreeze, do not get caught with this!
Ammonia water	NH_4OH	Household cleaning
Baking soda	$NaHCO_3$	Baking, fire extinguishers, medicines
Carbon tetrachloride	CCl_4	Fire extinguishers, cleaning fluid
Chloroform	$CHCl_3$	Anesthetic, solvent
Cream of tartar	$KHC_4H_4O_6$	Cooking, in baking powder
Dry ice	CO_2	Refrigeration
Glycerine	$C_3H_5(OH)_3$	Lotions, antifreeze, explosives
Limestone	$CaCO_3$	Building material, refining iron, fertilizers
Limewater	$Ca(OH)_2$	Making bleaching powder, water softening
Lye or caustic soda	$NaOH$	Cleaning, making soap
Plaster of Paris	$(CaSO_4)_2 \cdot H_2O$	Molds and casts, plastering
Quicklime	CaO	Mortar
Sand, silica, or quartz	SiO_2	Building, glass
Soap	$C_{17}H_{35}COONa$	Washing
Sugar, cane or beet	$C_{12}H_{22}O_{11}$	Food
Table salt	$NaCl$	Food, preserving food, chemical manufacturing
Vinegar	CH_3COOH	Flavoring, pickling foods
Washing soda	$Na_2CO_3 \cdot 10\ H_2O$	Washing, glass

3. Mixture: A mixture is any combination of different elements and compounds that are physically combined in any proportion, and they can be separated. Some common mixtures are air (large amounts of the elements nitrogen and oxygen, smaller amounts of the compounds carbon dioxide and water vapor), milk (water, fats, sugar, and other compounds), and soil. Of what do you think soil is composed?

SEE ACTIVITY 2.2

VII. Atoms: In the fourth century B.C., Democritus suggested that matter is composed of atoms (from the Greek word *atomos*, translated to "not able to be divided"). An atom is the smallest particle of an element that can exist and still have the same characteristics of that element.

A. Atomic theory: In the early 1800's, John Dalton proposed a theory which assumed that: (1) all matter is composed of atoms; (2) atoms cannot be subdivided; (3) atoms of an element are of the same size, shape, and mass; (4) atoms of an element differ in all properties from other elements; (5) when atoms are transferred between molecules or reordered within molecules, a chemical reaction occurs; and (6) atoms of one element are not changed into atoms of another element in a chemical reaction.

B. Characteristics of the atom: With the advent of the cyclotron (powerful atom smashers), scientists have been able to identify numerous subatomic particles. In the atomic theory, Dalton had proposed that atoms were indivisible. Now we know differently!

1. Subatomic particles: Only the three fundamental subatomic particles will be included here.

a) Electrons: An electron is a negatively charged subatomic particle. In 1897, Joseph Thompson identified the electron, measured its mass (almost 2000 times lighter than the hydrogen atom), and reasoned that it must be a part of the atom of all elements. The number of electrons equals the number of protons in a neutral atom. (See Figure 2.13).

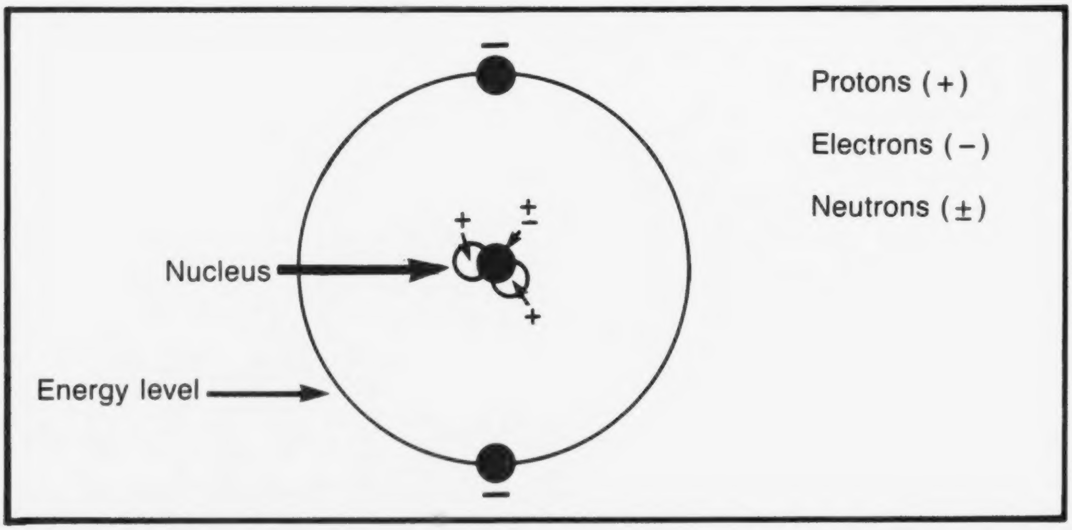


Figure 2.13. Structures of an Atom.

b) Protons: A proton is a positively charged subatomic particle. It is 1,840 times heavier than the electron. When the hydrogen atom loses its electron, the proton is what remains. The proton is located at the center of the atom as part of the nucleus. The number of protons in the nucleus determines the atomic number of the element. (See Figure 2.14)

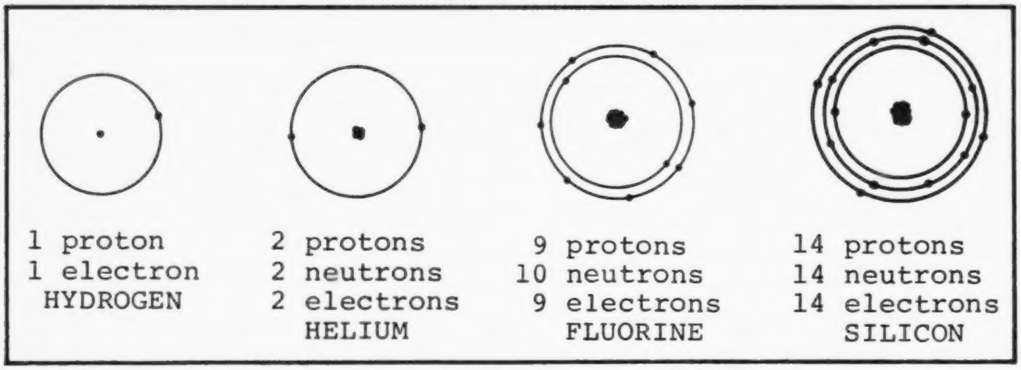
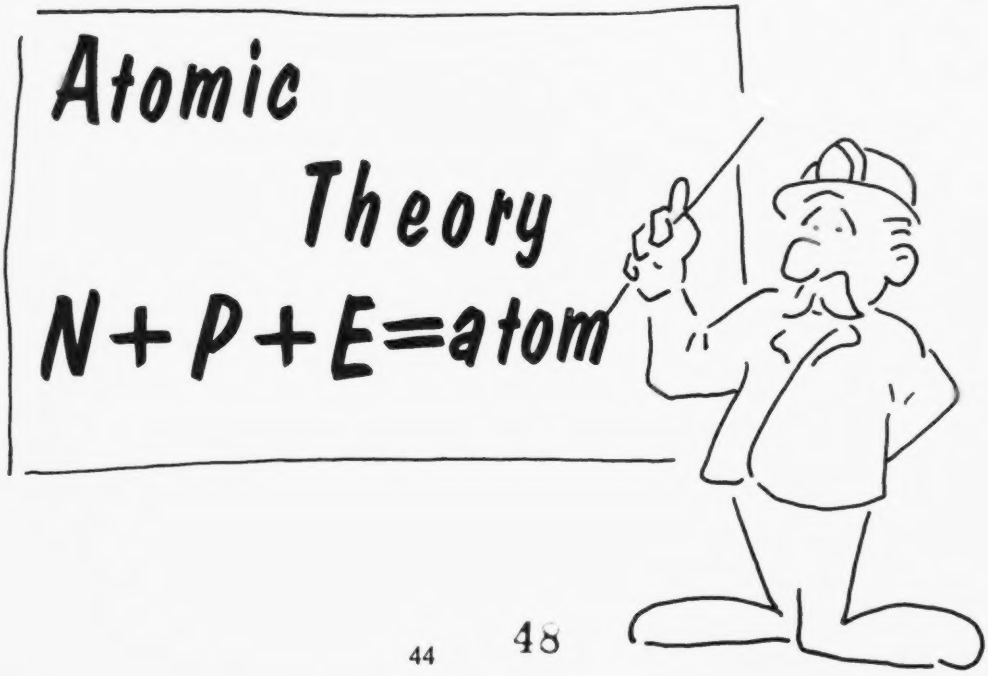

1 proton
1 electron
HYDROGEN
2 protons
2 neutrons
2 electrons
HELIUM
9 protons
10 neutrons
9 electrons
FLUORINE
14 protons
14 neutrons
14 electrons
SILICON

Figure 2.14. These diagrams represent some common atoms. The electron orbits are shown here in two dimensions, but they actually move in three dimensional spheres. While almost all of the mass of the atom is contained in the nucleus, the electron orbits take up between 20,000 and 200,000 times the radius of the nucleus.

c) Neutrons: Neutrons are subatomic particles having no change. They are located with the protons in the nucleus of the atoms. Of all the elements, hydrogen is the only one which has no neutrons. Neutrons have nearly the same mass as the protons. The number of neutrons plus the number of protons equals the atomic mass of the atom. Atoms of an element must contain the same number of protons, but the number of neutrons may vary. Any atom which differs from another only in the number of neutrons is called an isotope.


Atomic
Theory
N+P+E=atom

2. Atomic Models: When research results in a discovery that refutes a theory, a new theory (a better one, presumably) is proposed. Such is the case with the atom.
    a) The Rutherford Model: After scientists had proved the existence of protons and electrons (but before James Chadwick had confirmed the existence of the neutron), Ernest Rutherford proposed that the mass of the atom is concentrated in a densely packed region of the atom called the nucleus. Later, it was discovered that both protons and neutrons were subatomic particles found in the nucleus. Rutherford thought that the rest of the atom outside the nucleus, except for the very small electron, consisted of empty space.
    b) The Bohr Model: The idea that electrons occupy concentric, circular paths around the nucleus is attributed to Niels Bohr, a student of Rutherford. He also suggested that electrons have a fixed energy and are at energy levels (rings) around the nucleus. For an electron to change energy levels, it must lose (to fall inward to a lower energy level) or gain (to jump to a higher level outward from the nucleus) just the right amount of energy.
    c) The Quantum Mechanical Model: A quantum of energy is the necessary amount needed to cause an electron to jump to the next higher energy level. Quantum Mechanics gives us a highly sophisticated model of the atom and allows scientists to make quantitative predictions. The major difference between this model and the Bohr Model is in the calculated electron position. In the quantum mechanical model the energy levels are divided into sublevels, called orbitals. In the lowest energy level (ring one), there is only one sublevel (namely the "s" orbital) which may contain one or two electrons (atoms for the elements hydrogen and helium). The second energy level (ring two) has two sublevels, the "s" orbital which may hold a maximum of two electrons and the "p" orbital which may hold up to six electrons on three separate energy plateaus. As in the Bohr Model, the second energy level may contain as many as eight electrons, but the configuration is different.

       The high energy levels have additional sublevels (in addition to "s" and "p") of "f" and "d", and the placement of electrons becomes very complicated and rather unnecessary for us in our study here.
3. Atom differences and similarities: John Dalton suggested that atoms of one element are different from those of another element. Ways have been devised to measure the differences as well as show any similarities between atoms.
    a) Atomic number: The number of protons in the nucleus of the atom of an element simplifies the atomic number of that element. The carbon atom has six protons in the nucleus, therefore the element carbon is atomic number six.
    b) Atomic weight: Atomic mass is conventionally expressed as atomic weight. Scientists refer to the mass number (the total number of all the protons and neutrons in the nucleus) as the atomic weight. This weight is expressed in atomic mass unit (a.m.u.).
    c) Atomic mass units: In devising a scale of relative weights for atoms, the element oxygen was originally chosen as the standard and assigned value of 16 atomic mass units. Atoms of other elements were assigned relative weights in the same units.

       The existence of isotopes (differing number of neutrons in the nucleus) of oxygen caused complications in setting up this relative weight scale. Some scientists used the lightest and most abundant of these isotopes as standard, while others used the naturally occurring mixture of isotopes (oxygen) as standard. As a result, the scientific community ended up with differing standard (however slight the difference was).

C. Isotopes: Atoms of a given element having the same number of protons but different numbers of neutrons are referred to as isotopes. Isotopes are chemically alike because they have the same number of protons and electrons. There are two or more isotopes known for every element.

The atomic weight of zinc is 65.38. This weight (as shown in the Periodic Table) is an average value obtained from the mixture of zinc isotopes, and reflects the weight and ratio of the abundance of each isotope as it occurs naturally.

Some isotopes are unstable and are considered radioactive (give off subatomic particles). If the radioactive isotope gives off protons, then the element is altered and becomes other elements. Studies of the distribution of stable and unstable (radioactive) isotopes have given scientists insight into ages of rocks. Natural decay of the relatively abundant isotopes of potassium, uranium, and thorium is an important mechanism for generating heat which sets in motion forces which create many of earth's internal processes.

D. Electron configurations: The maximum number of electrons allowed on the first four energy levels outward from the nucleus is 2, 8, 18, and 32. Stability is established by electrons when they have assumed a position as close to the nucleus (lowest energy level) as possible.

The process of adding electrons to models of atoms proceeds in an orderly manner through the first (2 electrons) and the second (8 electrons) energy levels. For the third energy level, even though it can accommodate up to 18 electrons, stability is reached when the eighth electron is added, thus with atomic number 19 (potassium) electrons begin to fill the fourth energy level. When the fourth energy level has 2 electrons, the third energy level begins to receive electrons until it reaches the maximum of 18. Further additions is rather complicated.

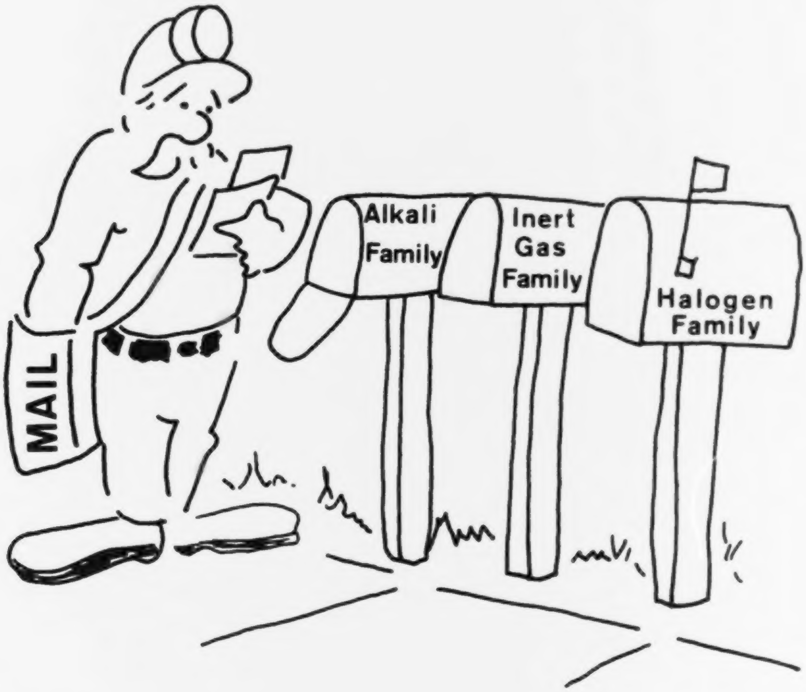
Valence electrons (those electrons occupying the highest energy level) determine the chemical properties of the element to a large extent. Filling the outside energy level is important in achieving stability in the atom.

VIII. Grouping of elements: As you recall, an element is a simple substance that cannot be broken down into a simpler substance by ordinary chemical means. Every element has its own (unique) atomic structure; its structure is different from all other elements. Because of this (unique) atomic structure, an element has its own (unique) properties. However, some of these properties are similar to the properties of other elements, so it is possible for scientists to group these like-elements.

A. Family: The Periodic Table (first constructed by Mendeleer and subsequently revised) is an arrangement of the elements according to similarities. The vertical columns are called families (or groups) and are classed by numbers and letters (4A). These elements have similar physical and chemical properties (same number of valence electrons in the outer, or highest, energy level). In the Periodic Table, one can determine the number of valence electrons for an element simply by finding the family number at the head of the column in which the element is located. Oxygen and sulfur, family 6A, have six valence electrons. The only exception to this is the family of "noble" gases, family 8A (sometimes listed as group 0), those elements whose highest energy levels are especially stable. Helium has 2 valence electrons, but all the others (neon, argon, krypton, xenon, and radon) in this family have 8 valence electrons. These inert gases are characterized by their refusal to combine with other elements. The following include some other examples of families:

1. Alkali metals: Lithium, sodium, and potassium are more familiar family members of the alkali metals. They react quickly with many elements and substances, so alkali metals are rarely found in nature of the pure state.

2. Halogens: This happy family has fluorine, chlorine, bromine, iodine, and astatine (Everyone knows about astatine!) in it. They love metals and easily unite with them to form different kinds of salts.

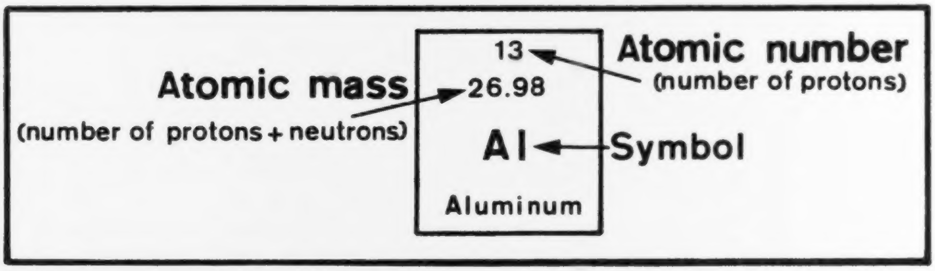


MAIL
Alkali Family
Inert Gas Family
Halogen Family

B. Periods: The horizontal rows in the Periodic Table are referred to as periods. all of the atoms of the elements in a period have the same number of energy levels, or electron orbits. Properties of the elements in the periods change from group to group, ranging in characteristics from metallic, to metal-like, to non-metallic, to gases.

C. Period table: By considering the atomic number (equal to the number of protons in the nucleus) and the family members, scientists have been able to compile a chart that includes all elements, each one in a separate box. The chart is called the periodic table. (See Table 2.3)

1. Arrangement within each box: Each element is represented by a chemical symbol. (See Figure 2.15) That symbol appears in the center of the box. The number at the top is the atomic number. (Remember? The number of protons in the nucleus!) The next number is the atomic mass of the element. Conventionally, it is referred to as the atomic weight.



13
26.98
Al
Aluminum
Atomic number
(number of protons)
Atomic mass
(number of protons + neutrons)
Symbol

Figure 2.15. An example of one box from the periodic table.

2. Arrangement of the periodic table: The periodic table is made up of all known elements, natural and man-made. (See Table 2.3) They are arranged in horizontal rows and vertical columns. A period consists of all the elements in one horizontal row. All of the elements in one period have the same number of electron orbits, or shells. The elements at the far left of the periodic table are elements that easily combine to make compounds. Moving from left to right across the table, the properties of each element change from characteristics of metallic, to metal-like, to non-metallic, to gases.

SEE ACTIVITY 2.3

IX. Chemical equations: You have learned that a chemical change results if a substance breaks down or combines to form a new substance. A chemical equation is a short, accurate description of a chemical change. To be precise, it must show the correct chemical makeup (formulas) of all the materials that enter into the change (reactants) and those that are produced in the change (products). If the equation is to be accurate, it must show that no atoms were gained or lost during the reaction; they were merely rearranged. When the equation does show this conservation, it is said to be a balanced chemical equation. This subject will aid you in understanding mineral formation.

A. Description of a chemical equation: There are a few basic rules and representations in a chemical equation. (See Figure 2.16)

$$\mathrm{Na} + \mathrm{OH} \rightarrow \mathrm{NaOH}$$

$$\mathrm{H_2} + \mathrm{O_2} \rightarrow \mathrm{H_2O} \quad \text{(not balanced)}$$

$$\mathrm{C} + 4\mathrm{H} \rightarrow \mathrm{CH_4}$$

Figure 2.16. Chemical equations.

1. Formula: A formula is an abbreviation that describes the chemical makeup of each substance involved in a chemical change.
2. Left side symbols: The symbols on the left side of the arrow represent the substances before the chemical change.
3. Right side symbols: The symbols on the right side of the arrow represents the products of the chemical change, the results.
4. Conservation of atoms: The equation must show the conservation of atoms; the number of each specific atom or atoms must be the same on each side of the arrow.
5. Lowered numbers: The lowered number following a symbol indicates the number of atoms. If there is no number, it is assumed that there is only one atom.
6. Numbers that precede symbols: The number before a symbol also helps indicate the number of atoms. If there is no number, it is assumed to be one.

B. Balancing a chemical equation: In Figure 2.16, the second example has two hydrogen atoms before and after the reaction. There are two oxygen atoms before the reaction but only one afterward. An oxygen atom was lost according to the formula, and that never happens (except to beginning chemistry students). Consequently, the formula needs to be balanced.

Table 2.3. Periodic Table

GROUP IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 1.0080 **H** Hydrogen																	2 4.003 **He** Helium
3 6.941 **Li** Lithium	4 9.012 **Be** Beryllium											5 10.81 **B** Boron	6 12.011 **C** Carbon	7 14.007 **N** Nitrogen	8 15.994 **O** Oxygen	9 19.00 **F** Fluorine	10 20.179 **Ne** Neon
11 22.990 **Na** Sodium	12 24.30 **Mg** Magnesium											13 26.98 **Al** Aluminum	14 28.09 **Si** Silicon	15 30.974 **P** Phosphorus	16 32.064 **S** Sulfur	17 35.453 **Cl** Chlorine	18 39.948 **Ar** Argon
19 39.098 **K** Potassium	20 40.08 **Ca** Calcium	21 44.96 **Sc** Scandium	22 47.90 **Ti** Titanium	23 50.94 **V** Vanadium	24 52.00 **Cr** Chromium	25 54.94 **Mn** Manganese	26 55.85 **Fe** Iron	27 58.93 **Co** Cobalt	28 58.70 **Ni** Nickel	29 63.55 **Cu** Copper	30 65.38 **Zn** Zinc	31 69.72 **Ga** Gallium	32 72.59 **Ge** Germanium	33 74.92 **As** Arsenic	34 78.96 **Se** Selenium	35 79.904 **Br** Bromine	36 83.80 **Kr** Krypton
37 85.47 **Rb** Rubidium	38 87.62 **Sr** Strontium	39 88.91 **Y** Yttrium	40 91.22 **Zr** Zirconium	41 92.91 **Nb** Niobium	42 95.94 **Mo** Molybdenum	43 (97) **Tc** Technetium	44 101.1 **Ru** Ruthenium	45 102.91 **Rh** Rhodium	46 106.4 **Pd** Palladium	47 107.868 **Ag** Silver	48 112.40 **Cd** Cadmium	49 114.82 **In** Indium	50 118.69 **Sn** Tin	51 121.75 **Sb** Antimony	52 127.60 **Te** Tellurium	53 126.90 **I** Iodine	54 131.30 **Xe** Xenon
55 132.91 **Cs** Cesium	56 137.34 **Ba** Barium	57-71 * **La-Lu** Below	72 178.49 **Hf** Hafnium	73 180.95 **Ta** Tantalum	74 183.85 **W** Tungsten	75 186.2 **Re** Rhenium	76 190.2 **Os** Osmium	77 192.2 **Ir** Iridium	78 195.09 **Pt** Platinum	79 197.0 **Au** Gold	80 200.59 **Hg** Mercury	81 204.37 **Tl** Thallium	82 207.2 **Pb** Lead	83 208.98 **Bi** Bismuth	84 (209) **Po** Polonium	85 (210) **At** Astatine	86 (222) **Rn** Radon
87 (223) **Fr** Francium	88 (226) **Ra** Radium	89-103 ** **Ac-Lw** Below	104 (261)	105 (262)	106												

* LANTHANIDE SERIES	57 138.91 **La** Lanthanum	58 140.12 **Ce** Cerium	59 140.92 **Pr** Praseodymium	60 144.24 **Nd** Neodymium	61 (145) **Pm** Promethium	62 150.35 **Sm** Samarium	63 152.0 **Eu** Europium	64 157.25 **Gd** Gadolinium	65 158.93 **Tb** Terbium	66 162.50 **Dy** Dysprosium	67 164.93 **Ho** Holmium	68 167.26 **Er** Erbium	69 168.93 **Tm** Thulium	70 173.04 **Yb** Ytterbium	71 174.97 **Lu** Lutetium
** ACTINIDE SERIES	89 (227) **Ac** Actinium	90 232.04 **Th** Thorium	91 (231) **Pa** Protactinium	92 238.03 **U** Uranium	93 (237) **Np** Neptunium	94 (244) **Pu** Plutonium	95 (243) **Am** Americium	96 (247) **Cm** Curium	97 (247) **Bk** Berkelium	98 (251) **Cf** Californium	99 (254) **Es** Einsteinium	100 (257) **Fm** Fermium	101 (258) **Md** Mendelevium	102 (259) **No** Nobelium	103 (260) **Lw** Lawrencium

Elements 1 - 92 are natural occurring.

1. Example #1: It is necessary to plug in numbers before each letter or group of letters in order to balance an equation. Start with the formula $H_2 + O_2 \text{ --> } H_2O$. Place a 2 in front of H_2O. Then you have $H_2 + O_2 \text{ --> } 2H_2O$. Multiply the number in front of the symbol by the lowered number following the symbol. Now you have two oxygen atoms before and two after the reaction. But, if you multiply the 2 in front of H_2O by the 2 following the H, you get 4. That means there are 2 hydrogens before the reaction and 4 after.

   That is not conservation, either. However, if you plug in a 2 before the H_2, you have (miracle of miracles) the 4 hydrogen atoms before and after. The final result is then $2H_2 + O_2 \text{ --> } 2H_2O$. Sometimes it is necessary to experiment back and forth before determining the correct balance.
2. Example #2: This will follow the balancing procedure again, step-by-step.

		Before	After	
Step 1	$KClO_3 \text{ --> } KCl + O$	1K	1K	balanced
		1Cl	1Cl	balanced
		3O	2O	not balanced
Step 2	$2KClO \text{ --> } KCl + 3O_2$	2K	1K	not balanced
		2Cl	1Cl	not balanced
		6O	6O	balanced
Step 3	$2KClO_3 \text{ --> } 2KCl + 3O_2$	2K	2K	balanced
		2Cl	2Cl	balanced
		6O	6O	balanced

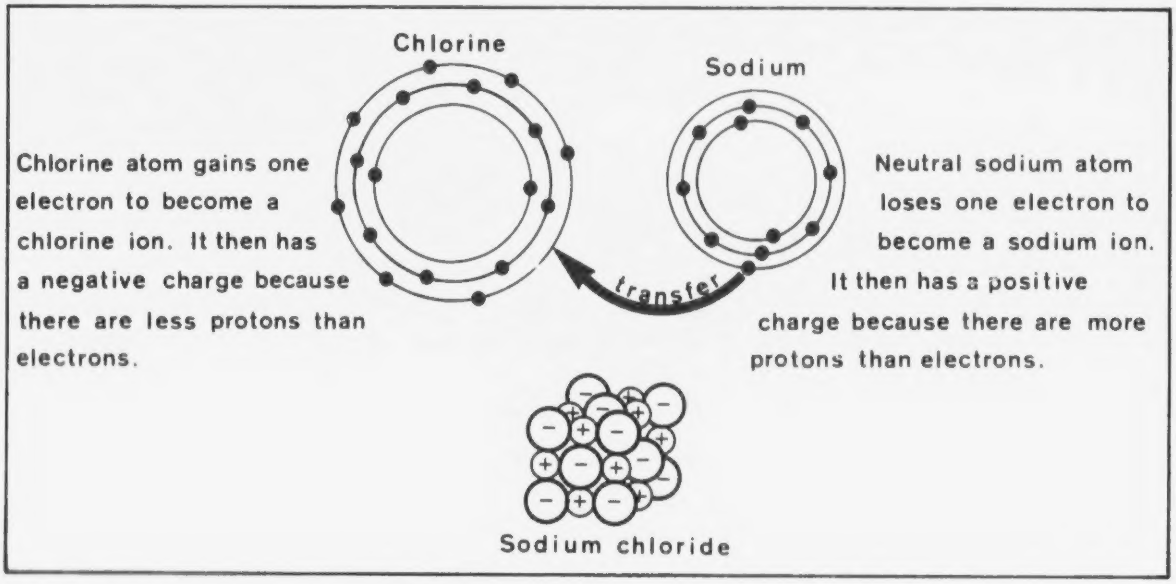
SEE ACTIVITY 2.4

X. Chemical bonding: A chemical change can always be recognized by the creation of a new substance. It always involves the combining of two or more elements. A few facts must be understood before discussing the different types of chemical combining.

A. Arrangement of electrons in atoms: You have learned that there are few elements found in a pure state in the earth's crust. Nearly all of them are found as compounds. The smallest number of a compound that can exist is a molecule. (Remember that the smallest unit of an element is an atom.) Each compound is composed of just one kind of molecule. The electron arrangement of an atom determines which atoms will join to form a molecule. If an atom loses or gains an electron as a result of the energy of heat or light, it becomes positively or negatively charged. Charged atoms of this sort are called ions.

B. Types of chemical bonds: For a molecule to be created, two or more different atoms must be held together by an attractive force called a chemical bond. Chemical bonding can occur in one of three ways.

1. Ionic bonding: This is a stable arrangement of atoms that occurs when electrons are transferred, given up by one atom and received by another. An atom is stable and content if it has eight electrons in its outer-most shell. (An exception to this is in the case of elements that have no more than a total of two electrons. In this situation, they are stable with two electrons in their only shell.) If an atom does not have eight electrons in its outer shell, it is unstable and will easily bond with another atom to become stable. For example, the chlorine atom has seven electrons in its outer shell orbit. The sodium atom has one electron in its outer shell. (See Figure 2.17)



Chlorine atom gains one electron to become a chlorine ion. It then has a negative charge because there are less protons than electrons.

Neutral sodium atom loses one electron to become a sodium ion. It then has a positive charge because there are more protons than electrons.

Figure 2.17. In ionic bonding, ions are formed by the completions of an electron ring by the gain or loss of electrons. In this illustration, sodium chloride, or salt, is created by ionic bonding. The unlike charges hold the ions together.

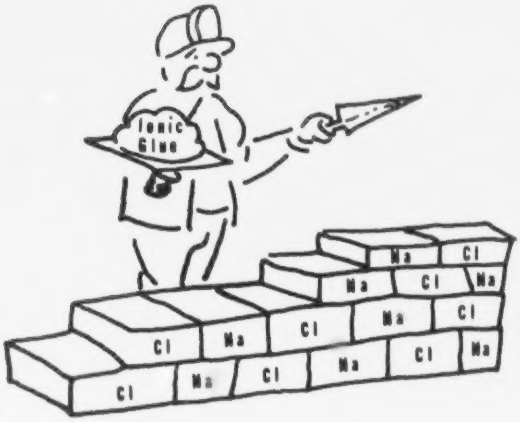
The electron in the outer shell of the sodium atom is transferred to the outer shell of the chlorine atom, resulting in both atoms possessing eight electrons in their outer shells. Because the sodium atom lost an electron, it becomes a positively charged ion because it has more protons than electrons. The chlorine atom gained an electron to become a negatively charged chlorine ion because it has fewer protons than electrons. This type of bonding creates most minerals. It occurs between elements on periodic table groups I and II, and groups VI and VII because they have either one or two electrons in their outer shell, or six or seven electrons in their outer shell. There are two products of ionic bonding with which you may be more familiar.

a) Acids: These are compounds in which one or more hydrogen (H) atoms have combined with one or more other atoms. One acid of importance in geology is carbonic acid. Carbon dioxide combines with rainwater to form a weak acid which then dissolves some types of rocks. The formula for this process is:

$$\underset{\text{(water)}}{H_2O} + \underset{\text{(carbon dioxide)}}{CO_2} \dashrightarrow \underset{\text{(carbonic acid)}}{H_2CO_3}$$

b) Bases: These are compounds that have one or more groups of oxygen and hydrogen (OH) atoms combined with one or more other atoms. A typical formula for this is:

$$\underset{\text{(sodium)}}{Na} + \underset{\text{(hydroxide)}}{OH} \dashrightarrow \underset{\text{(sodium hydroxide or lye)}}{NaOH}$$



2. Covalent bonding: Rather than electrons being transferred as in ionic bonding, they are shared by two or more atoms in covalent bonding. As was stated before, atoms are stable with a qualified two electrons or, most often, eight electrons in the outer shell. By sharing electrons, a stable arrangement can be made. (See Figure 2.18) Because of their particular electron arrangement of three, four, or five electrons in the outer shell, groups III, IV, and V on the periodic table join by covalent bonding.

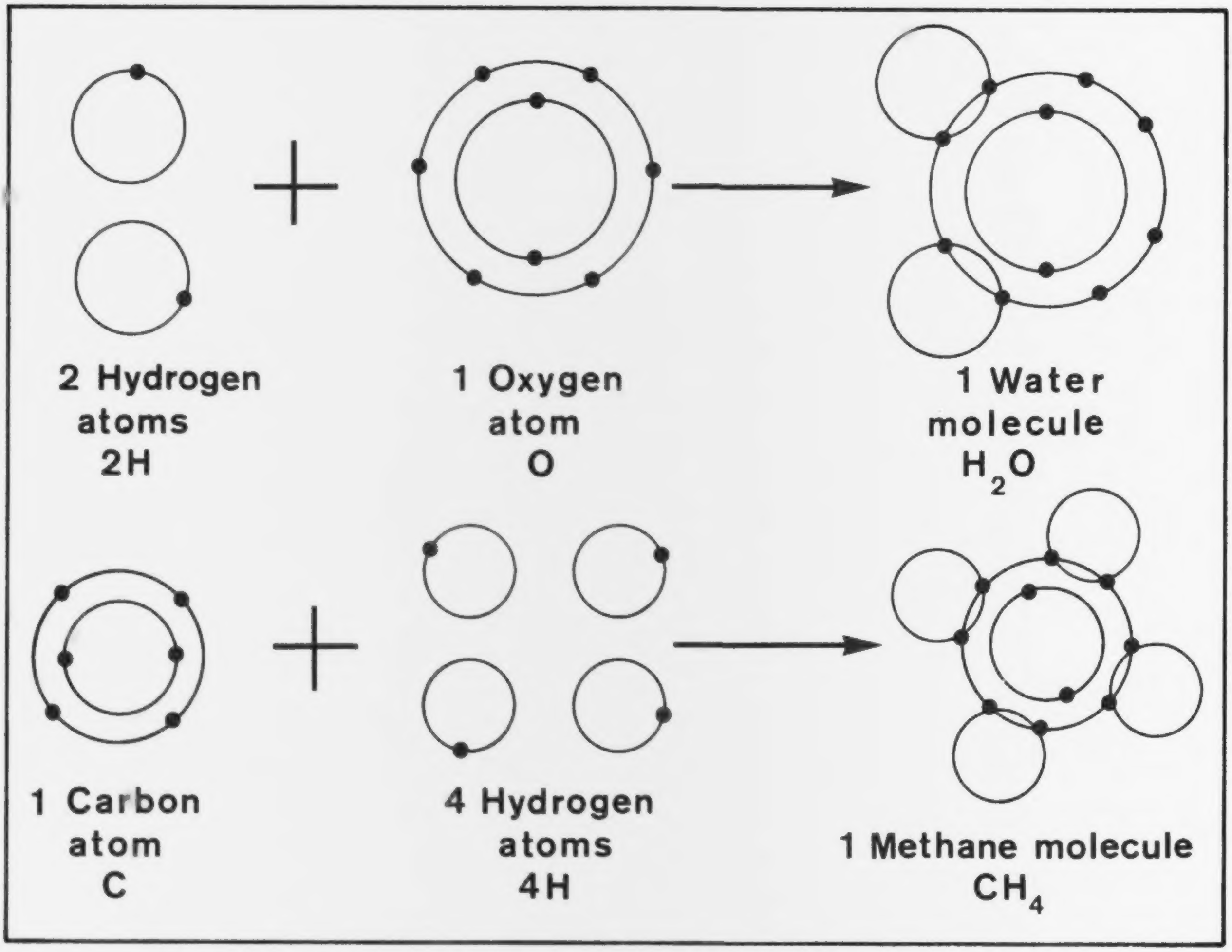


Figure 2.18. Illustrates how covalent bonding results when electrons are shared by more than one atom.

3. Metallic bonding: A third common type of bonding is the metallic bond. In a metal, the atoms are closely packed so that the electrons are not owned by any particular nucleus. This allows the electrons to move rather freely through the metal, making it possible for metals to conduct electricity.

XI. Summary: If atoms could talk, the secrets of the universe, stars, solar systems, and earth would be totally revealed. Atoms have "seen it all," and they hold the answers for which mankind has always yearned. Since the answers are not available for the asking, man has simply had to work from within his own framework of knowledge. As the subject matter is narrowed down from the universe to a closer frame of reference such as earth, the answers, while still not complete, come with more frequency and with more assurance of accuracy. As man's horizons expand through space travel, more answers will be unveiled, no doubt some as shocking as Christopher Columbus' discovery that the world is not flat. The thrill of discovery will be the driving force that will feel mankind's eternal quest for knowledge.

Chapter 2: Problems and Questions

1. Compare (likenesses) and contrast (differences) the states of matter. Give two (2) specific examples of each.
2. Explain the differences in a physical change of matter and a chemical change of matter.
3. Relate elements, compounds, and mixtures to one another. Give three (3) examples of each.
4. Describe the structure of an atom.
5. What kind of information does a chemical formula contain?
6. Discuss the types of chemical bonding. Include information on why bonding occurs.
7. Explain the grouping of elements, and list three (3) groups.
8. Why must a chemical equation "balance"?
9. Briefly explain the steady state theory and the big bang theory in describing the origin of the universe.
10. Explain the origin and evolution of a star.
11. Discuss the origin of the solar system according to the proto-planet theory and the encounter theory.
12. Relate the following terms to one another: planets, moons, universe, stars, suns, solar systems, and matter.
13. Make a list of ten (10) specific facts about the earth.
14. Describe the various layers of the earth. With each layer, include the composition and states of matter.

Unit II: Earth Materials

CHAPTER 3: Minerals

I. Introduction

II. Minerals

III. Mineral-forming Environments
  A. Internal Formation
    1. Plutonic Igneous Environment
    2. Pegmatitic Environment
    3. Hot Water Vein Environment
      a) High Temperature Vein
      b) Moderate Temperature Vein
      c) Low Temperature Vein
    4. Metamorphic Environment
  B. External Formation
    1. Groundwater Environment
    2. Weathering Environment
    3. Sedimentary Environment

IV. Mineral Grouping
  A. Silicates
  B. Carbonates
  C. Oxides
  D. Sulfides
  E. Halides
  F. Sulfates
  G. Phosphates
  H. Native Elements

V. Mineral Identification
  A. Physical Properties
    1. Color
    2. Streak
    3. Hardness
    4. Luster
    5. Crystal Form
    6. Cleavage
    7. Fracture
    8. Specific Gravity
    9. Tenacity
    10. Transmission of Light
    11. Other Physical Properties
  B. Chemical Properties
  C. X-ray Analysis

VI. Common Rock-forming Minerals
  A. Feldspar
  B. Quartz
  C. Mica

Mineral Magic

    D. Ferromagnesium Minerals
    E. Clay Minerals
    F. Calcite

VII. Et Cetera
    A. Ore Minerals
    B. Gems
        1. Diamonds
        2. Rubies and Sapphires
        3. Emeralds and Aquamarines
        4. Semiprecious Stones

VIII. Summary

Related Activities

Vocabulary

Develop classification system for earth materials.

Identify minerals.

Problems and questions

Mineral Geo Facts

Minerals were first used as weapons, then for ornamentation, and finally for industry.

Egyptians mined turquoise over 5,000 years ago. It was probably the first semiprecious stone to be mined on a large scale. On the Sinai Penninsula, Egyptians employed 2,000 to 3,000 miners in the turquoise mines. The mining was conducted with the use of stone tools and other primitive implements.

Most United States' quartz is imported from Brazil.

At the General Electric Research Laboratories, a smear of peanut butter was placed in a high pressure chamber. Shortly, they removed a tiny diamond.

Mineralogy has existed as a science for a short time, beginning about 1800.

Chapter 3: Word List

Mineral Mouthfuls

Aggregate
Bowen's Reaction Series
Brittle
Calcic
Carbonate
Cleavage
Conchoidal fracture
Continuous series
Crystal
Crystal face
Crystalline structure
Discontinuous series
Effervesce
Elastic
Evaporite
Flexible
Fracture
Groundwater
Halide
Heft
Magma
Malleable
Microcrystalline
Mineral
Mineral hardness
Mineral-forming environment
Native element
Ore mineral
Opaque
Oxide
Pegmatite
Phosphate
Physical property
Polymorph
Precipitation
Rock
Sectile
Silicate

Sodic
Specific gravity
Sulfate
Sulfide
Tenacity
Translucent
Transparent
Vein
Weathering

Straight Terms

Abrasion
Aggregate
Amorphous
Classification
Concentric
Environment
Foliated
Granular
Impurity
Inorganic
Resinous
Simulate
Stable
Striated
Tetrahedron
Volatile

UNIT II: EARTH MINERALS

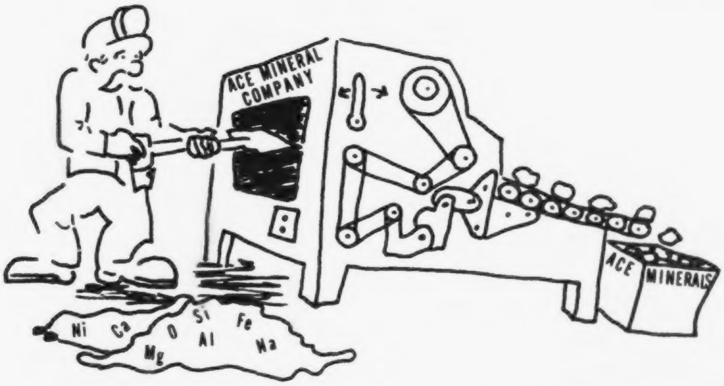
Chapter 3: Minerals

I. Introduction: In Chapter 2, you had a brief introduction to chemistry to prepare you, not only to better understand the various origins described, but also to understand minerals and rock formation. Chapter 3 will introduce you to minerals. A brief overview is given of mineral-forming environments and mineral grouping. Next, you will have the opportunity to identify materials. The chapter then concludes with a description of common rock-forming minerals, ore minerals, and gems.

II. Minerals: Minerals are naturally occurring elements or compounds of an inorganic nature. They have a characteristic atomic structure, a definite chemical composition, and specific physical properties. Since there are 92 naturally occurring elements, the number of combinations possible to produce minerals is great. Some of the most common mineral-producing elements include oxygen, silicon, aluminum, iron, magnesium, calcium, sodium, and potassium. Between 2,000 and 2,500 minerals (depending upon how picky the classifications are) can be found in the earth's crust, but only eight minerals are common. (See Table 3.1) The gems and metals, such as diamonds and aluminum, with which most of us are familiar make up only a small percentage of the earth's crust.

Table 3.1. Percentage (by Volume) of Common Minerals in the Earth's Crust

Plagioclase feldspar	39%	Amphiboles	5%
Quartz	12%	Micas	5%
Orthoclase feldspar	12%	Clay minerals	5%
Pyroxenes	11%	Other silicates	3%
		Nonsilicates	8%



III. Mineral-forming environments: Minerals form in a definite response to their environment, and most do so beneath the earth's surface at depths far too great for man to observe. However, from studying the minerals at or near the surface of the earth, it is possible to piece together a picture of the conditions (the environment) under which minerals were formed. Much of what is known about the formation of minerals is based upon the findings of laboratory experiments which simulate earth conditions at those great depths. There are several conditions under which minerals form (mineral-forming environments), and they can do so within a rock mass or on or near the earth's surface. (A rock is an aggregate of minerals).

   A. Internal formation: This is any location of formation far below the surface of the earth.

      1. Plutonic igneous environment: A large mass of very hot liquid materials (magma) forces its way upward into solid rock. (See Figure 3.1) The molten mass cools very slowly so that the different minerals within the molten mass can congregate. The individual minerals, because they can cool slowly, form large chunks, and the result is large, coarse-grained minerals. Examples of resulting minerals:

Biotite	Muscovite
Feldspar	Pyroxene
Magnetite	Quartz

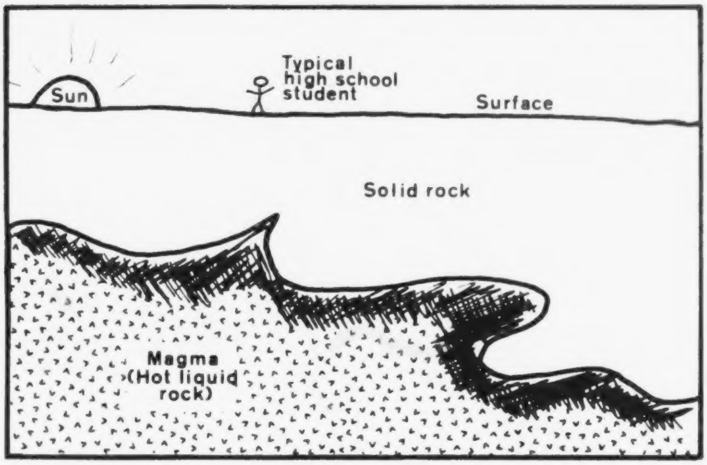


Figure 3.1. An illustration of a plutonic igneous environment. Hot liquid rock forces its way up into solid rock and cools slowly.

2. Pegmatitic environment: After most of the liquid rock has solidified, the remaining liquid rock fills any cracks that formed during the cooling process. The pressure of the volatiles found within the cooled magma provides a driving force to inject some remaining liquid along weak areas into the surrounding rocks. This forms teardrop or tabular-shaped masses called pegmatites. (See Figure 3.2) Pegmatite material cools very slowly, permitting the growth of extremely large mineral chunks. Many gems and rare minerals occur in a pegmatite in addition to some more common minerals. Examples of resulting minerals:

Apatite
Biotite
Corundum
Feldspar
Fluorite
Muscovite
Quartz
Pyroxene
Topaz
Tourmaline

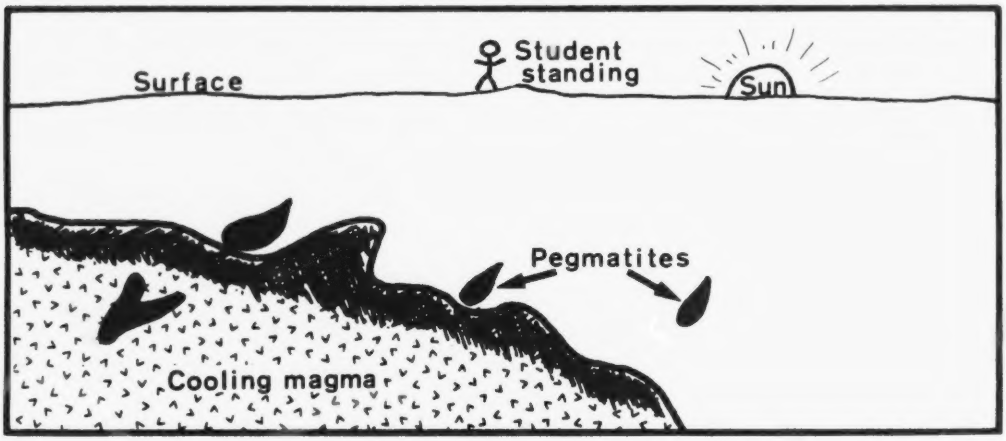


Figure 3.2. Illustrates a pegmatitic environment. The black, tear-shaped objects are pegmatites. Most were injected into the surrounding solid rock.

3. Hot water vein environment: Hot water, in addition to some acids and dissolved metals, drives its way through cracks or fractures (veins) in the surrounding rocks. It can travel for long distances from the main mass of magma. The fluids recombine chemically with the minerals in the walls of the fractures and form new minerals. Hot water veins are broadly grouped into three types and grade one into another. (See Figure 3.3)
   a) High temperature vein: Deposits of this type form at fairly high temperatures of 300° to 500° Centigrade (572° to 932°) at considerable depths in the earth's crust and very near the magma. Examples of resulting minerals:

Cassiterite
Chalcopyrite
Copper
Gold
Pyrite
Wolframite

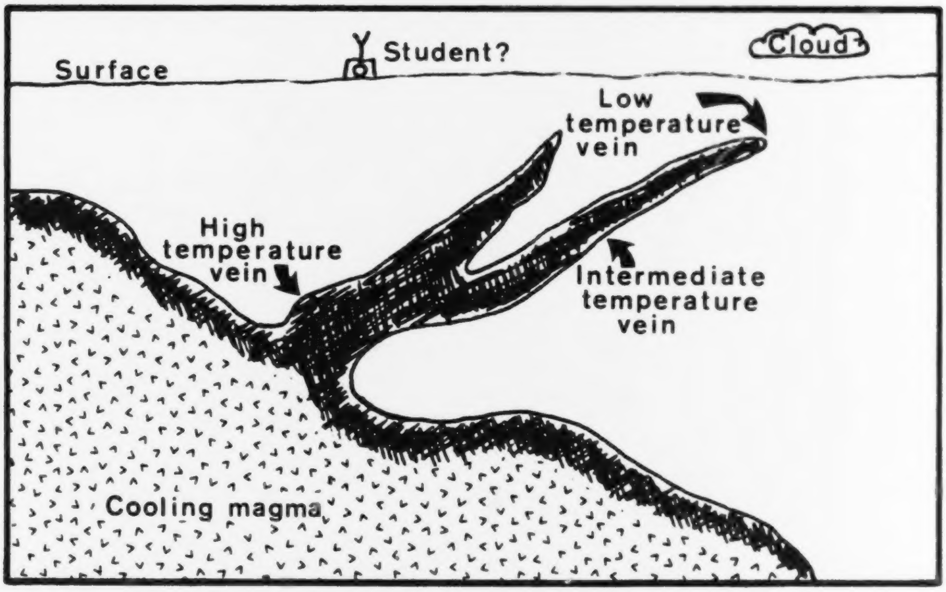


Figure 3.3. Illustrates hot water vein deposits. Shown are the different types of veins determined by their location.

b) Moderate temperature vein: These deposits are farther from the main mass of hot magma and are therefore cooler at 200° to 300° Centigrade (392° to 572°). Examples of resulting minerals:

- Calcite
- Chalcopyrite
- Copper
- Galena
- Gold
- Pyrite
- Quartz
- Sphalerite

c) Low temperature vein: Farthest from the source of heat, these deposits form at relatively cool temperatures of 50° to 200° Centigrade (122° to 392°F). Examples of resulting minerals:

- Barite
- Calcite
- Chalcedony
- Copper
- Fluorite
- Galena
- Gold
- Pyrite
- Quartz
- Sphalerite
- Sulfur

4. Metamorphic environment: Metamorphism is the sum of the processes that cause rocks to change into new assemblages of rocks and minerals. The rocks remain solid but change due to differences in temperature, pressure, and chemical environment. (See Figure 3.4) Because of these changes, the physical and chemical stability of the rock is affected so that the constituents of the rock are changed to minerals of a more stable nature. Examples of resulting minerals:

- Calcite
- Garnet
- Graphite
- Hematite
- Magnetite
- Mica
- Quartz
- Talc

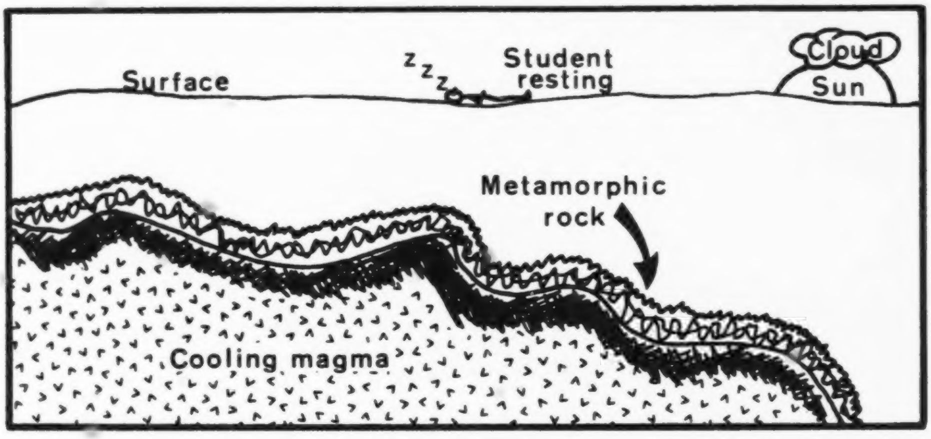

Surface
zzz
Student resting
Cloud
Sun
Metamorphic rock
Cooling magma

Figure 3.4. Illustrates a metamorphic environment. Rocks along the edge of a once liquid mass are subject to physical and chemical changes, producing new textures and new minerals.

B. External formation: This is any location of formation on or near the surface of the earth.

1. Groundwater environment: Groundwater is the part of rainwater that seeps through the soil, filling cracks and other openings in beds of rock. As rainwater falls, it combines with carbon dioxide in the atmosphere and soil to form a weak acid. This process is expressed in the following formula: $CO_2 + H_2O \dashrightarrow H_2CO_3$. As the acid now contained in the groundwater trickles through carbonate rocks such as limestone, dolomite, and marble, it dissolves some minerals leaving cavities in the rock. The water works down through these cavities, dissolving and changing the minerals as it goes. (See Figure 3.5) The groundwater then deposits a whole new group of water-formed minerals. Examples of resulting minerals:

Aragonite
Calcite
Travertine

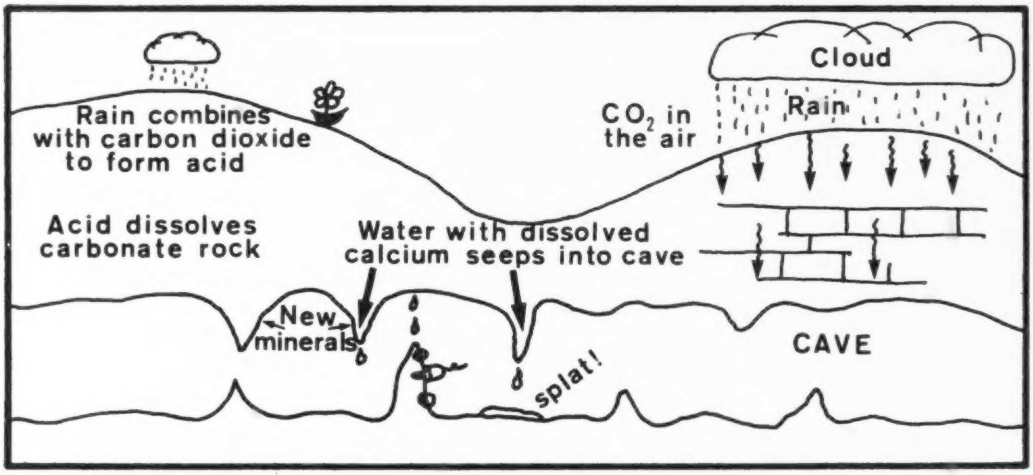

Rain combines with carbon dioxide to form acid
Cloud
CO_2 in the air
Rain
Acid dissolves carbonate rock
Water with dissolved calcium seeps into cave
New minerals
CAVE
splat!

Figure 3.5. An illustration of groundwater environment. Rain combines with carbon dioxide to form a weak acid which dissolves carbonate rock. The water with dissolved minerals then deposits these minerals in a different form creating a new mineral.

2. Weathering environment: Weathering is the breakdown of rocks or minerals at or near the surface of the earth because of the interaction of the atmosphere, water, and plant and animal life. When air and water come in contact with minerals exposed at the surface, some of them change in composition. Different elements and compounds are now available to form new chemical combinations and thus new minerals. (See Figure 3.6) Examples of resulting minerals:

Azurite
Barite
Bauxite
Clay minerals
Hematite
Limonite
Malachite

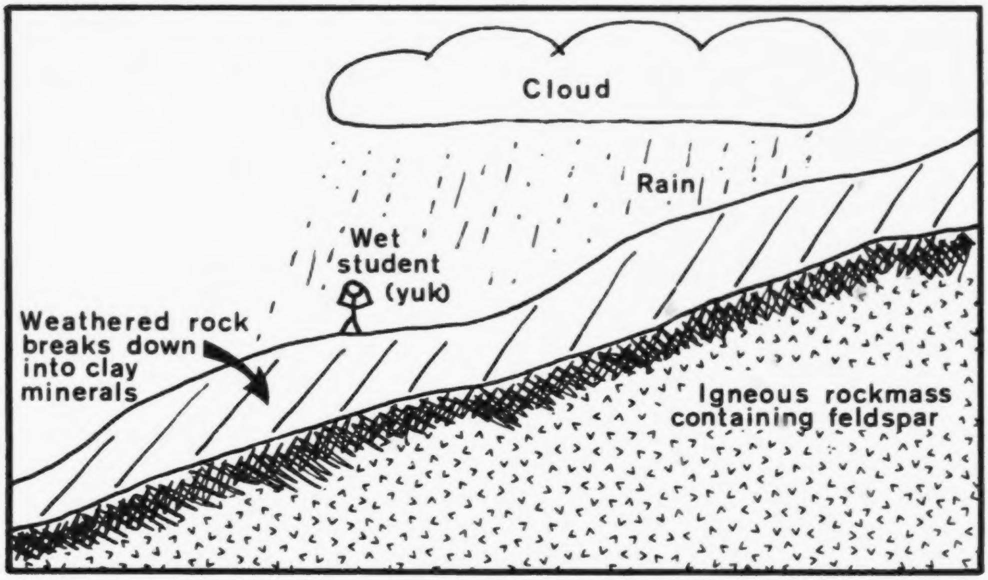

Cloud
Rain
Wet student (yuk)
Weathered rock breaks down into clay minerals
Igneous rockmass containing feldspar

Figure 3.6. An illustration of weathering environment. Weathering on or near the surface of the earth chemically changes the rock present into different minerals. The darkened area in the figure indicates an area where a solid rock is beginning to weather because of its nearness to the surface of the earth.

3. Sedimentary environment: Streams and groundwater carry material dissolved by other processes and suspended mineral matter to lakes or seas. There, new minerals may form by their precipitation or settling to the bottom of the water body. (See Figure 3.7) Sometimes, the water will evaporate, and the process is responsible for deposits called evaporites (noted by * below). Examples of resulting minerals:

Calcite
Flint
*Gypsum
*Halite
Hematite
Limonite
Pyrite
Quartz

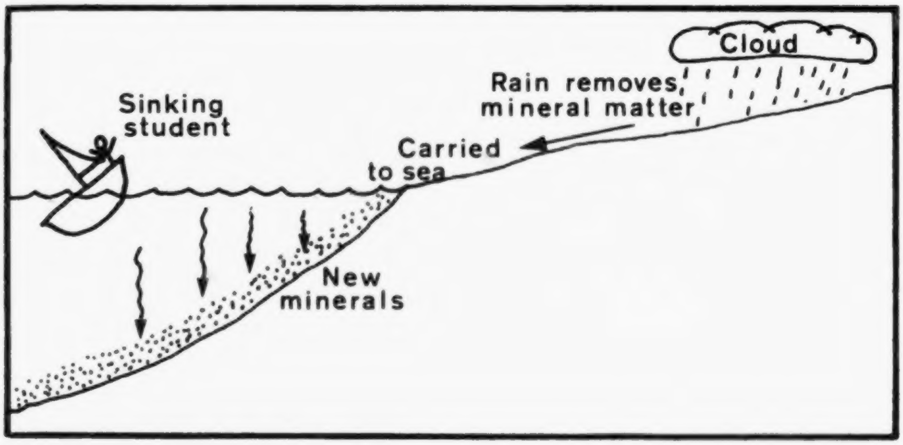


Figure 3.7. An illustration of sedimentary environment. Streams and groundwater carry away mineral matter and deposit it in standing bodies of water where new minerals are then formed.

IV. Mineral grouping: Minerals can be divided into groups on the basis of their composition.

A. Silicates: About one-third of all minerals are silicates. They are minerals composed mainly of silicon and oxygen. In all the silicate minerals, the chemical bonds between the silicon and oxygen are so strong that the four oxygens are always found at the corners of the tetrahedron molecule with the silicon in the middle. (See Figure 3.8) Because of the various types of additional atom arrangements, it is possible to have many different silicate minerals. Examples of silicate minerals:

Amphibole
Clay
Feldspar
Mica
Olivine
Pyroxene
Quartz

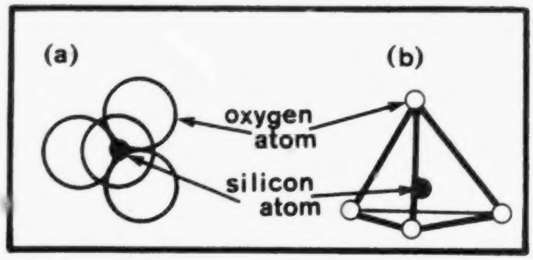


Figure 3.8. (a) is the SiO_4 tetrahedron showing the silicon atom surrounded by four oxygen atoms. (b) illustrates the atoms reduced in size to show their arrangement in a clearer manner.

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B. Carbonates: Carbon and oxygen form the unit CO_3, which then combines with other elements to form carbonates. Examples of carbonate materials:

Calcite
Dolomite

C. Oxides: Included in this group are compounds in which one or more metallic elements are combined with oxygen. Examples of oxide minerals:

Hematite
Magnetite

D. Sulfides: There are minerals composed of a larger atom of sulfur and a smaller atom of one or more metals. It is because of this arrangement that most sulfides are metallic in character. Examples of sulfide minerals:

Chalcopyrite
Galena
Pyrite
Sphalerite

E. Halides: These minerals are compounds of the halogen elements fluorine, chlorine, bromine, and iodine. Examples of halide minerals:

Fluorite
Halite

F. Sulfates: Sulfur and oxygen form the unit SO4 to combine with other elements. Examples of sulfate minerals:

Anhydrite
Gypsum

G. Phosphates: Phosphorus and oxygen form the unit PO_4 and combine with other elements. Examples of phosphate minerals:

Apatite
Turquoise

H. Native elements: There are a number of chemical elements that are found in their uncombined states as minerals in the solid part of the earth's crust. However, none of them occur in masses large enough to be classified as rocks. Some of these elements have always attracted people's attention. Examples of native elements:

Copper
Gold
Silver
Sulfur

MINERALS
GROUPS
OXIDE
HALIDE
SULFIDE

V. Mineral identification: Minerals can be identified by studying their composition and crystal structures which determine the properties of the mineral. Learning which properties are characteristic of each mineral is necessary in mineral identification.

  A. Physical properties: These are the characteristics of minerals that describe the minerals through physical observations. They are of great help in identifying minerals.

    1. Color: Although color is often relied upon in identifying minerals, it is not always very accurate. A mineral may be various colors because of impurities. An excellent examples of this is quartz, an abundant mineral which may be clear, milky, grey, smoky, rose, purple, yellow, or red. However, in a few minerals, color is valid but should be observed on a fresh surface. Examples are pyrite (brassy yellow), sulfur (bright yellow), malachite (green), and azurite (blue).
    2. Streak: This reveals the color of the powder of a mineral. If it is rubbed across unglazed porcelain, called a streak plate, the mineral is powdered and leaves a streak. The color of the streak may be different from the color of the mineral because the impurities that change the color of the mineral do not affect the color of the streak. Of course, those minerals which are harder than the porcelain (equal or greater than 7 on the hardness scale) will not leave a powder, so this test becomes inadequate. Different iron minerals are often confused because they are the same color. In this case, the streak test proves helpful in identification. Magnetite leaves a grey-black streak; hematite leaves a reddish streak; limonite leaves a yellowish-brown streak. Minerals that have a nonmetallic luster have a white or pastel streak; therefore, streak is not useful in distinguishing the nonmetallic minerals.
    3. Hardness: Hardness is a mineral's resistance to abrasion or how easily it can be scratched. A harder mineral will scratch a softer mineral. Minerals of equal hardness will scratch each other. Table 3.2 shows the relationship between ten different minerals and various common objects (a copper penny, a piece of glass, a knife, etc.) that are handy for testing, *Note that the scale is relative*. The steps do not represent equal degrees of hardness. For example, gypsum is not twice as hard as talc. The important function of the hardness scale is to show that any mineral on the scale will scratch all of the minerals below it.
    4. Luster: This characteristic is the way light is reflected from the surface of a mineral. Several varieties are recognized. (See Table 3.3)
    5. Crystal form: Solids have a regular, orderly arrangement of their internal atoms. This is known as the crystalline structure of crystal form. If the mineral is able to grow in an unrestricted space, it may develop the external shape of the crystalline structure, a crystal. Table 3.4 lists the six basic crystal systems. Each flat crystal surface corresponds to a plane of atoms in the crystal structure. The flat surface is known as a crystal face. Unfortunately, crystals often cannot grow in open, unobstructed space. When found, well-formed crystal structure tells us much about the internal structure and greatly aids in the identification of the mineral.
    6. Cleavage: This is the tendency of crystals to break along definite smooth planes. That these planes exist is a simple indication of the difference in strength of bonds between atoms in an element. If the bonds are very strong between the atoms in one plane and relatively weak between those in another plane, they will more easily break along the planes of weakness in the mineral. One, two, three, four, or six cleavage directions are possible. (See Figure 3.9) They can be recognized by their smoothness and tendency to form pairs or steps which will reflect light.

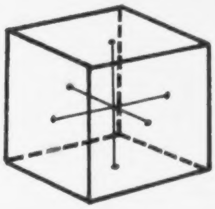
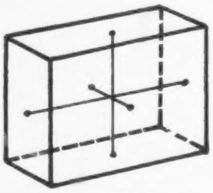
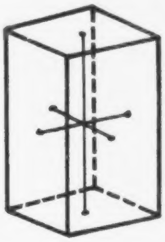
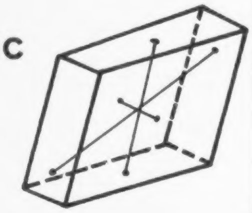
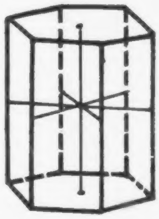
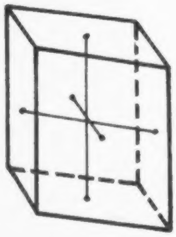
Table 3.2. Moh's Scale of Hardness

	RELATIVE NUMBER IN THE SCALE	MINERAL	HARDNESS OF REFERENCE OBJECTS
Decreasing ↓	10	Diamond	
	9	Corundum	
	8	Topaz	
	7	Quartz	Steel file
	6	Orthoclase	Pocket knife, glass
	5	Apatite	
	4	Fluorite	
	3	Calcite	Copper penny
	2	Gypsum	Fingernail
	1	Talc	

Table 3.3. Types of Luster and Examples

	LUSTER	EXAMPLE
	Metallic	Galena
Nonmetallic	Glassy	Quartz
	Pearly	Talc
	Resinous	Sphalerite
	Waxy	Flint
	Brilliant	Diamond
	Silky	Asbestos
	Greasy	Graphite
	Dull or Earthy	Limonite

Table 3.4. Crystal Forms and Examples

Isometric (Cubic) Galena 	**Orthorhombic** Barite 
Tetragonal Chalcopyrite 	**Monoclinic** Mica 
Hexagonal Quartz 	**Triclinic** Plagioclase Feldspar 

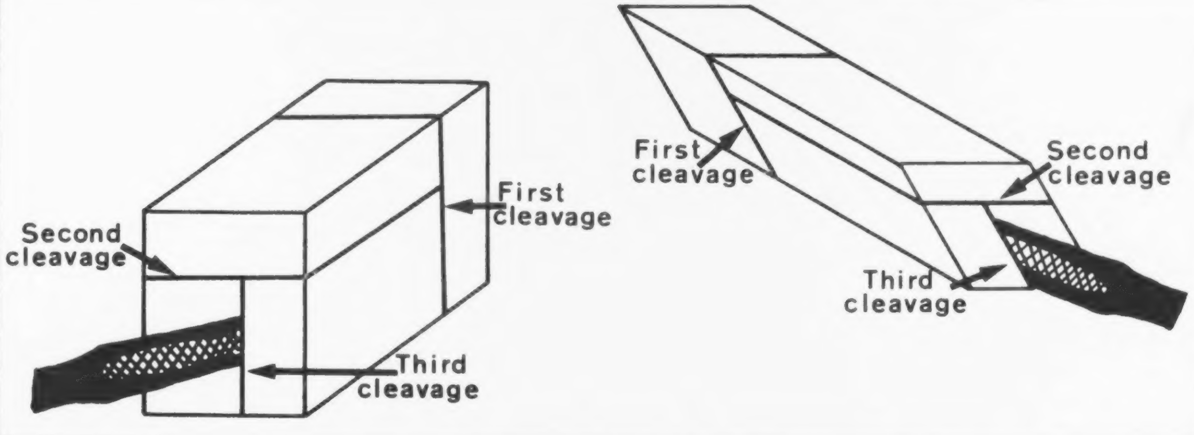

Second cleavage
First cleavage
Third cleavage
First cleavage
Second cleavage
Third cleavage

Figure 3.9. Illustrates two types of cleavage. On the left, the three cleavage planes lie perpendicular to each other. On the right, the planes are at other than right angles.

7. Fracture: Any irregular break in a mineral is called a fracture, and it can occur in any direction. A common type of fracture is a hollow, rounded type of break like that sometimes seen in glass and is known as a conchoidal fracture. Quartz exhibits this type of fracture.
8. Specific gravity: This represents the weight of a mineral in comparison to an equal volume of pure water. For example, a mineral with a specific gravity of 4 is four times as heavy as water. Minerals with numerous and compact atoms will have higher specific gravity. Most rock-forming minerals are around 2.6, compared to 19.3 for gold and 7.6 for galena. Metallic minerals tend to be heavier than nonmetallic ones. You can hand test (called hefting) for relative specific gravity by lifting various minerals.
9. Tenacity: This is the way a mineral breaks or becomes deformed under stress. (See Table 3.5)

Table 3.5. Types of Tenacity and Examples

TENACITY	EXAMPLE
Brittle (breaks into fragments when hit)	Quartz
Malleable (flattened into a thin wire)	Native metals such as copper
Sectile (cut by a knife into thin shavings)	Selenite gypsum
Flexible (bendable, not regaining original shape)	Talc
Elastic (bendable, regaining original shape)	Mica

10. Transmission of light: This is the ability of a mineral to transmit light. A mineral can be transparent (light travels through and a distinct image can be seen), translucent (light travels through but no images are seen), and opaque (no light is transmitted). For examples, a transparent mineral would be some form of clear calcite; a translucent mineral would be clear quartz; and an opaque mineral would be talc.
11. Other physical properties: In addition to the previously mentioned properties that make identification by sight possible, there are several characteristics that aid mineral identification. Magnetism is one way to identify the mineral magnetite. Halite will taste salty. Clays emit an earthy odor when moistened. Talc will have a greasy feel when rubbed. Some clear calcite will produce a double image. Other minerals are radioactive in their natural state and can be detected by a Geiger counter.

B. Chemical properties: By conducting various chemical behavior, on a mystery mineral, one can observe its chemical behavior, determine the chemical composition of that mineral, and thereby possibly identify the mineral. However, this is not always trustworthy, because two minerals may have the same composition but a different internal structure. This would result in a different mineral, or a polymorph. An example is diamond and graphite. They are both composed of carbon, but because of the different arrangement of atoms, they are two distinct minerals. There are many different tests available for use in mineral identification. However, you will be doing only one--the acid test for calcite and dolomite. When diluted hydrochloric acid is placed on calcite, the mineral will effervesce (make bubbles). Dolomite will also bubble but only if the mineral is powdered.

CAUTION: Hydrochloric acid is harmful to the tongue and teeth. After the acid has been applied to the mineral, blot the mineral specimen dry. The next tester may use the taste test.

C. X-ray analysis: The atoms of a mineral are arranged in an orderly manner. Each mineral has a specific atomic arrangement. X-rays of the mineral indicate the internal structure and thereby identify the mineral. Needless to say, this procedure is not used by beginning geology students.

To Tell the Truth
Will the real Henry Hematite please stand?

VI. Common rock-forming minerals: Of the numerous minerals which occur in the earth's crust, only a few are abundant. These are considered to be the common rock-forming minerals. (Again, a rock is an aggregate of minerals.) An American physical chemist named Bowen was able to determine that when molten rock (magma) cools, certain minerals form at specific temperatures. He put the information into chart form called Bowen's Reaction Series. (See Figure 3.10) At the top of the diagram, we find the minerals that first crystallize at very high temperatures (olivine and calcic plagioclase). At the bottom, we see quartz which crystallizes last at relatively low temperatures. On the right side of the diagram, we notice a continuous series occurs; that is, minerals continuously crystallize without abrupt changes. For example, the calcic plagioclase crystals grade into the sodic plagioclase crystals. On the left side, we find a discontinuous series; that is, the changes from one mineral to the next occur in definite steps. For example, first olivine crystals form. Then when the magma cools a small amount, pyroxene crystals form. On the following page is a more detailed description of the minerals that commonly form rocks.

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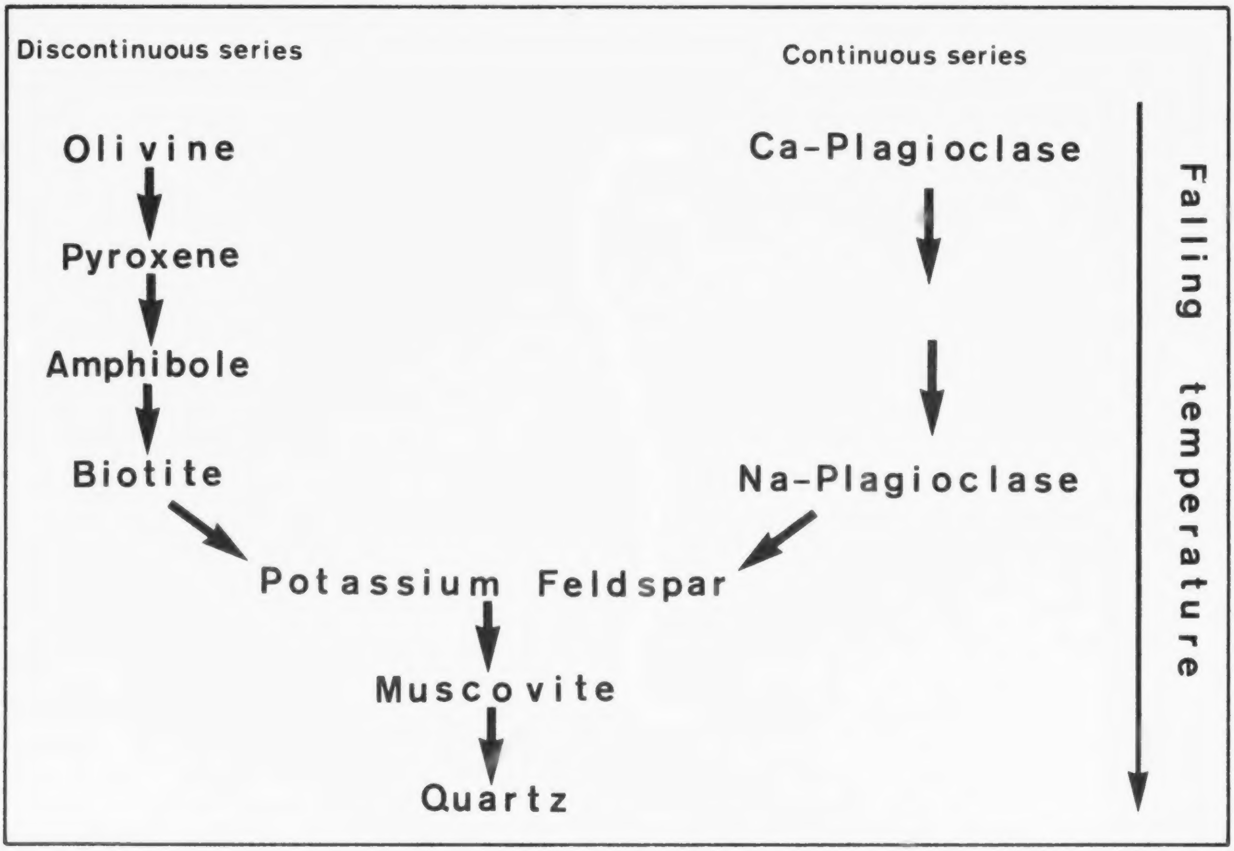

Discontinuous series
Continuous series
Olivine
Pyroxene
Amphibole
Biotite
Ca-Plagioclase
Na-Plagioclase
Potassium Feldspar
Muscovite
Quartz
Falling temperature

Figure 3.10. Bowen's Reaction Series. The diagram shows the general sequence of mineral formation within molten rock as the temperature falls.

Rock Formers
MINERALS
ROCK
ROCK

A. Feldspar: This is the most abundant mineral and therefore a very important mineral in the earth's crust. In addition to its importance as a rock former, clay is largely the product of weathered feldspars. Feldspars are used extensively in the manufacturing of ceramic products and are a common ingredient in scouring powder. Orthoclase feldspar is generally light in color. Plagioclase feldspar can be calcic (dark in color due to the presence of calcium) or sodic (light in color due to the presence of sodium). These variations are possible because sodium and calcium ions are about the same size and can therefore replace each other.

B. Quartz: The second most abundant mineral, quartz, is generally clear or white, but it may have numerous colors resulting from impurities. Types of quartz include clear, milky, smoky, rose, amethyst, and citrine. In addition, there are microcrystalline (How's that for a long word?) varieties of quartz with crystals too small to be seen with the unaided eye. These include agate and jasper. Quartz is a difficult mineral to alter or destroy because its atoms are stable. It is commonly used as an abrasive (Why do you think that is?) and also in the manufacturing of glass. As a very common mineral in sand, it is then used in concrete, plaster, and mortar.

C. Mica: Mica has two common varieties. Biotite mica is dark, usually black in color. Muscovite mica is white in color. Because muscovite is flexible, elastic, low in thermal conductivity, difficult to melt, and electrically nonconducting, it is unique and therefore essential in industry. It is used as insulation in electrical devices. Muscovite can also be used as a lubricant or, in powdered form, as dust to prevent rubber goods, asphalt roofing, and asphalt tiles from sticking together.

D. Ferromagnesium minerals: Magnesium and iron are the essential ingredients of these minerals, in addition to silicon and oxygen. The minerals are dark green to black in color. They include olivine, pyroxene, amphibole, and biotite, and are listed in Bowen's Reaction Series in Figure 3.10. They have little economic value.

E. Clay minerals: Formed at the earth's surface, clay minerals are created by the interaction of air and water with silicate minerals. An example is kaolinite, which weathers from aluminum silicates, especially feldspar. The ceramic industry makes frequent use of clay minerals.

F. Calcite: Calcite is usually either white or transparent, but it can be various colors because of impurities. When some of the calcium is replaced by magnesium, the mineral dolomite results. Calcite has a wide variety of uses. In its clear, transparent form, it is of value for optical purposes. It is beneficial in chemical industries. In addition to being used as a fertilizer, calcite is also an important ingredient in making Portland cement.

VII. Et cetera: (In other words, subjects that do not fit into the above categories.)

A. Ore minerals: These are mineral deposits containing enough metals to make the mining of them profitable. In this chapter, we will only mention a few important ones. Three ores of iron include hematite, magnetite, and limonite. Because hematite is abundant, it is the most important ore of iron. Magnetite has a high iron content, but it is rather rare. Limonite is an ore that results from the weathering of other iron minerals. Native ores include copper, silver, and gold. Additional ores and their products include those listed in Table 3.6. Ores are vital to our world today and will be discussed in the chapter on mineral resources.

Table 3.6. Ore Minerals and Products	
ORE	PRODUCT
Sphalerite	Zinc
Cinnabar	Mercury
Galena	Lead
Chalcopyrite, Malachite, and Azurite	Copper
Cassiterite	Tin

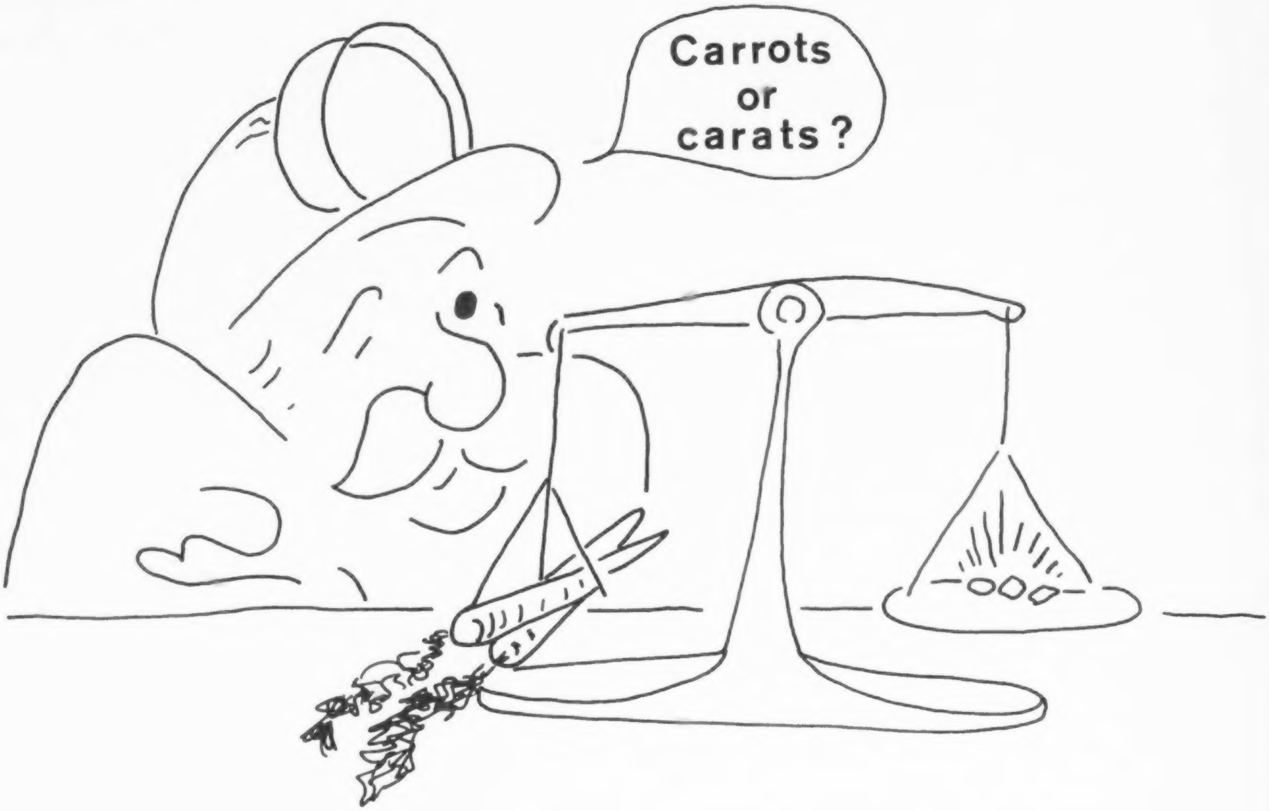
B. Gems: Some rather rare but fascinating minerals include the gemstones. Gems have a high value ($) largely because of their popularity and resulting demand. They are usually scarce, able to disperse light, have a pleasing color, and are hard and durable. Precious gems include diamonds, rubies, emeralds, and sapphires.

1. Diamonds: "Diamonds are a girl's best friend." They are the most popular gem in North America and also among the most expensive. (Is that why they are a girl's best friend?) They are composed only of the element carbon, but they have developed under extremely high temperatures and pressures. Diamonds that are not of gemstone quality are used in industry as abrasive or cutting edges because of their extreme hardness.
2. Rubies and sapphires: Corundum, with a hardness of 9, is the source of rubies and sapphires. Rubies are red to purplish in color. Excellent rubies are equal in value to diamonds. All other colors of transparent corundum are called sapphires.

3. Emeralds and aquamarines: Beryl gems produce these beauties. Emeralds are green and very valuable. Aquamarines are blue to blue-green. All natural beryl gems contain flaws that are especially noticeable in large emeralds.
4. Semiprecious stones: Quartz gems include amethyst, citrine (yellow), smoky, rose, and rock crystal. Opal is an amorphous (no crystalline arrangement) variety of quartz and ranges from semiprecious to precious. Agate, carnelian, and other varieties of microcrystalline quartz are considered semiprecious stones. Garnets, spinels, topaz, zircons, turquoise, and peridot (clear olivine) are also considered semiprecious gems.

SEE ACTIVITY 3.1

SEE ACTIVITY 3.2


Carrots or carats?

VIII. Summary: Until this year, there is a good possibility that when you have observed a mineral, first of all, you called it a rock. (BOO! HISS!) Secondly, you probably were interested in it from a standpoint of its appearance. Upon completion of this chapter, your approach to mineral study should be more sophisticated. You now know the basics of chemistry and chemical bonding that created the minerals in and on the earth. You are familiar with the environments under which various minerals form. You can now identify many minerals with more assurance than before. You can name the minerals that commonly form rocks. Armed with this knowledge, you are now ready to proceed to the next chapter on rocks.

Extra Reading: If you are interested in further reading, the article, "Origin of Geodes," published by the Illinois State Geological Survey, ends the chapter.

Origin of Geodes

Geodes are usually globular although they also may be irregular, discoid, or sometimes shaped very much like fossils. They are usually found in limestone, but they may also form in shaly rocks. Most of them are hollow, but many have become filled with minerals growing from the walls inward.

A typical geode sawed or broken in two will disclose a sequence of layers from the outside-in as follows: (1) a thin clay layer; (2) a layer of noncrystalline chalcedony; (3) crystals (usually quartz) projecting into the hollow interior. Less commonly calcite or dolomite crystals will form next to the outer chalcedony layer instead of quartz, and sometimes the inside of a geode will be nothing but chalcedony; and (4) a deposit of minor minerals, commonly as crystal druses of pyrite, ankerite, magnetite, hematite, kaolin, aragonite, millerite, chalcopyrite, sphalerite, limonite, smithsonite, malachite, gypsum, fluorite, barite, marcasite, geothite, pyrolusite, and possibly tenorite and chalcocite. Perhaps the most thought provoking and rarest of geodes are those which contain petroleum or some thicker bituminous material.

By what processes and under what conditions did these interesting features originate? There are many theories, none of which are completely adequate. The following discussion is an attempt to compile some of them into a brief summary.

First of all, it is generally agreed that geodes are cavity fillings. The agreement ends here, for the stumbling block is the origin of the initial cavity. One idea is that the cavities are "vugs" caused by gas pockets or by shrinkage of the rock. However, vugs are integral parts of the rock in which they are contained, whereas geodes are complete entities which can be broken out of the rock formation with comparative ease. Some geologists have suggested that they are merely special types of concretions, but geodes grow from the outer shell inward, whereas concretions build up from a central core. Bassler (1908, pp. 133-154) has shown that some geodes originate in fossil cavities and upon growth of the geode, the fossil bursts. Upon further growth, the fragments of the fossil are dissolved or absorbed by the growing geode and are lost. Van Tuyl (1916, pp. 34-42) believes that the original cavity is the space which was occupied by a concretion. Concretions are easily removed from the rock by percolating waters and would thus leave a likely cavity in which a geode could grow. The fact that some geodes contain calcerous clay concretions lends support to this theory.

Pettijohn (1957, pp. 204-205) give a rather complex process by which geodes grow after the formation of an initial cavity. This process may be summarized in the following steps: (1) a cavity is formed in the rock by some means; (2) a salty solution fills the cavity and pore spaces in the rock; (3) a layer of gelatinous silica is then deposited, isolating the salt solution in the cavity; (4) later the water in the surrounding pore spaces becomes fresh. This sets up what is known as an osmotic cell. This particular osmotic cell consists of two different types of solutions separated by a membrane of gelatinous silica which will allow the fresh solution to pass into the geode cavity, but will not allow the salt to pass out of it; (5) the fresh water flowing into the cavity by osmosis builds up internal pressure which pushes on the walls of the geode; (6) this pressure, exerted outward against the surrounding limestone, dissolves the limestone, leaving an insoluble residue which becomes the thin clay layer on the outer surface of the geode; (7) the above process continues until the salt solution is so diluted by the incoming fresh water that the osmotic cell no longer operates. The geode has reached maturity; (8) gradually the silica gel dehydrates and crystallizes; (9) shrinking and cracking then follow; (10) finally, mineral-bearing waters flowing through the cracks deposit the innermost layer of minerals. These cracks may eventually seal, leaving a completely closed geode.

The process by which some of the geodes of the Warsaw beds came to contain petroleum is also very much a mystery. Frank Fleener (1961) gives an interesting account of the problem. He envisions the petroleum having migrated up into the Warsaw Formation from the oil-bearing rocks to the south. There partially formed geodes were found with loose quartz crystals (some doubly terminated) adrift in the thick bitumen. The influx of the bituminous material stopped the growth of the geodes, but the mechanism by which the bitumen was enclosed and hermetically sealed remains a matter of conjecture. We believe that many of these geodes are hermetically sealed because the bituminous material will sometimes squirt out with force when the geode is punctured. This phenomenon is presumably due to the sudden expansion of the material when the pressure under which it was formed is relieved.

A more plausible explanation for the petroleum is that it was derived from the enclosing shale and shaly limestone. The weight of overlying sedimentary rocks could easily have freed hydrocarbons from the organic matter in the shale and shaly limestone. The hydrocarbons then migrated to zones of lowest pressure, and these most likely would be the cavities inside the geodes. It appears that such a pressure difference would exist because the hard shell of the geode could withstand a great amount of lithostatic pressure.

The above discussion of the origin of geodes is incomplete and generalized, but we hope that it will stimulate interest in these remarkable features. Perhaps as you break them open in search of beautiful crystals, you will reflect upon their history and feel a greater appreciation for the intricate processes by which nature is continuously altering the crust of the earth.

References

Bassler, R. S., *The Formation of Geodes,* with Remarks on the Silicification of Fossils: National Museum Proc., vol. 35, 1908, pp. 133-154.

Fleener, Frank L., *Our Fascinating and Enigmatic Geodes:* Earth Science, vol. 14, no. 1, Feb. 1961. pp. 24-27.

Pettijohn, F. J., *Sedimentary Rocks,* Harper and Brothers, New York, 1957, pp. 204-205.

Van Tuyl, F. M., *The Geodes of the Keokuk Beds:* American Journal of Science, Series 4, vol. 42, 1916, pp. 34-42.

Chapter 3: Problems and Questions

1. Given an unknown mineral, describe the process you would use to identify it.
2. Compare and contrast the properties of color and streak.
3. Explain how minerals are classified into various groups.
4. Define a rock-forming mineral. Describe four (4) of them.
5. What characteristics must a mineral have to be classified a "gem" mineral? Name five (5) gem minerals.
6. Compare the following terms: atom, element, mineral, compound, and rock.
7. Discuss Bowen's Reaction Series and its importance to mineral formation.
8. Are minerals being created at this time? If so, give three (3) examples of where minerals might be forming.
9. What are chemical properties of minerals? Describe one (1).
10. What characteristics must a mineral have to be considered an ore mineral? List four (4), and state the ore that is obtained from each.
11. What is meant by a mineral-forming environment? Discuss three (3) environments.

Unit II: Earth Materials

CHAPTER 4: Rocks

I. Introduction

II. Igneous Rocks
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      a) Concordant Features
        (1) Sill
        (2) Laccolith
      b) Discordant Features
        (1) Dike
        (2) Batholith
        (3) Stock
    2. Extrusive or Volcanic Features
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      b) Phaneritic
      c) Porphyritic
      d) Glassy
      e) Vesicular
    2. Composition
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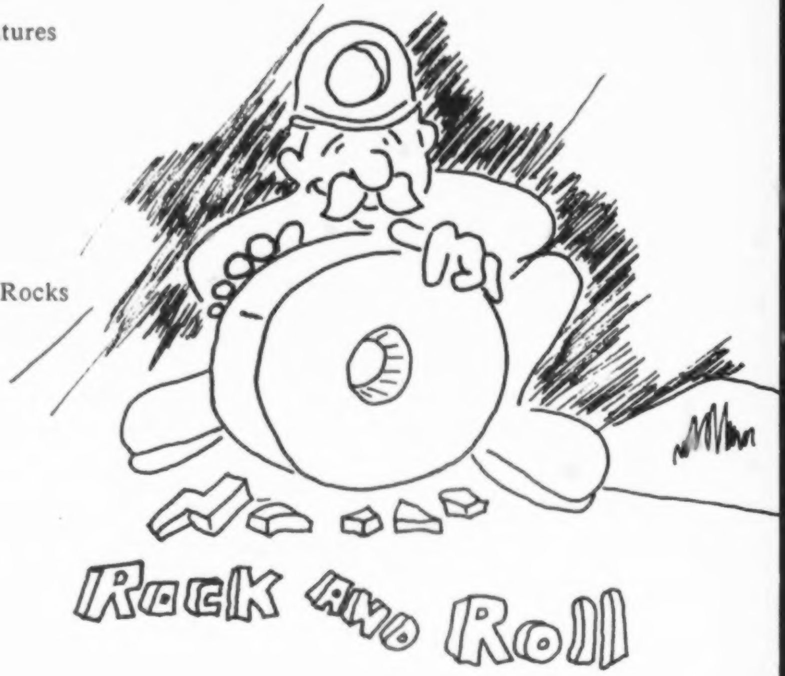
      b) Diorite
      c) Peridotite
      d) Gabbro
      e) Anorthosite
      f) Syenite
    2. Extrusive
      a) Basalt
      b) Obsidian
      c) Tuff
      d) Rhyolite
      e) Andesite
      f) Scoria



III. Sedimentary Rocks
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      b) Detrital
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      a) Chemical Precipitate
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    - 3. Recrystallization
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      b) Phyllite
      c) Schist
      d) Gneiss
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      b) Quartzite
      c) Hornfels
      d) Anthracite Coal

V. Rock Cycle

VI. Geologic Time on Earth
  A. Historical Background of the Geologic Time Scale
  B. Relative Time Scale
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  D. Geologic Time Scale

VII. Summary

Related Activities

Vocabulary

Identify intrusive features.

Identify igneous rocks.

Identify sedimentary rocks.

Identify metamorphic rocks.

Measure geologic time by scale on paper.

Problems and Questions

Rock Geo Facts

Obsidian was used by the Indians as knives, arrow points, and spears. The Mound Builders of the Ohio Valley prized obsidian and made trips to the area of Yellowstone National Park to obtain supplies of it.

Conglomerates are often called pudding-stones because they resemble fruit in an old-style plum pudding.

Chert and its varieties are probably found in every strata of every time period and in every part of the world.

Soapstone is sometimes called potstone because Indians and other Stone Age people carved it into dishes and pots for cooking.

Sedimentary rocks cover three-fourths of the land surface.

Most sedimentary rocks represent a reworking of the earth's crust.

Rocks and minerals are not stable. They change with their environment.

Chapter 4: Word List

Rocky Terms

Absolute time
Acidic
Aphanitic
Basic
Batholith
Bedding plane
Cementation
Clastic
Compaction
Concordant feature
Contact metamorphism
Cross-bedding
Crystallize
Cut-and-fill feature
Delta
Deposition
Detritus
Dike
Discordant feature
Environment
Epoch
Era
Erosion
Evaporite
Extrusive feature
Felsic
Foliated texture
Fossiliferous
Geologic time scale
Glassy texture
Gneissic layering
Graded bedding
Half-life
Igneous rock
Impermeable
Index fossil
Intrusive feature
Laccolith
Lagoon
Lava
Lithification
Mafic
Magma
Metamorphic rock
Microcrystalline
Mud crack
Nodule
Non-foliated
Nonclastic
Oolite
Oolitic texture
Organic reef
Overburden
Period
Permeability
Petrology
Phaneritic texture
Phenocryst
Plutonic feature
Porosity
Prophyritic texture
Recrystallization
Regional metamorphism
Relative time
Replacement
Ripple mark
Rock
Rock cycle
Schistosity
Sediment
Sedimentary rock
Sill
Slaty cleavage
Sorting
Strata
Stratification
Texture
Transitional environment
Varve
Vesicle
Volcanic feature
Weathering
Well-sorted

Straight Terms

Adjacent
Aggregate
Agitation
Calcareous
Chronological
Consolidate
Continental
Decompose
Elongate
Evolution
Evolve
Froth
Humanoid
Marginal
Marine
Organic
Relative (adj.)
Sheered
Soluble
Stagnant
Void
Vulnerable
Whew! Finished!

Harry made fun of my rock collection so I dumped it!

UNIT II: EARTH MATERIALS

Chapter 4: Rocks

I. Introduction: Since man has been around, he has had an awareness of rocks. In fact, the Stone Age of man's evolution was named as such because of the uses early man made of rocks. To use rocks, man first had to study them; thus began petrology--the study of rocks. Rocks are a part of the earth's crust and are made up of a mineral; or an aggregate of minerals, formed over a large area. A few, such as coal, are made of minerals which are not minerals but rather organic material. Rocks are the major materials forming the crust and mantle of the earth. From a study of the mineral composition, texture (grain size), and structure (arrangement of particles) of a rock, a geologist can usually determine some part of its history. With study, it becomes clear that there are different rock types. Some show definite layering; some are very coarse combinations of crystals with angular shapes; and some show apparent cementation of grains into a mass. By considering all of the information obtained by field and laboratory studies, geologists have grouped the many different rocks into three main categories--igneous, sedimentary, and metamorphic.

II. Igneous rocks: The word igneous comes from the Latin translation meaning "made from fire." (And, hot fires they are!) Igneous rocks form when various minerals melt together, cool, and then solidify. This hot mass of molten rock is called magma. Although a great deal has been learned about magma and the manner in which it solidifies (crystallizes) into a variety of rock types, knowledge about its source is scant because all of its forming processes occur far below the earth's surface. Magmas are not generated everywhere within the crust and upper mantle, nor are they continuously being created in any one place. They seem to occur where cracks, perhaps caused by stress, tap mantle regions in areas of high temperatures thereby relieving pressure and allowing rocks to flow upwards as liquids. There are three specific places this may occur: (1) at lithospheric plate boundaries, especially in subduction zones where one plate slides under another; (2) at the mid-ocean ridges where, in the process of sea-floor spreading, the magma flows upward into the fracture; and 93) at "hot spots", or centers of volcanic activity within a plate, over a rising mantle plume. It might be pointed out that the average composition of the outer 10 to 20 kilometers (6 to 12 mi) of the earth's crust is igneous rocks, and the total amount of sedimentary and metamorphic rocks is insignificant in comparison.

  A. Igneous rock environments: Environments include all of the surrounding things that affect the development of whatever is being considered. Your geology class environment includes the geology room, the equipment, the class members, the teacher, the temperature, etc. Rocks form in definite environments. As was mentioned before, knowledge about magma is limited. However, it is believed that magma must begin from the local melting of solid rock in the lower crust and upper mantle.

NOTE: For a more complete study of these features, please refer to Chapter 11, *Volcanic Activity.*

1. Intrusive or plutonic features: If magma fails to reach the earth's surface, it remains under a great deal of pressure. In an attempt to move to areas of less pressure, it may squeeze its way into, around, or through existing rock before cooling. Those structures formed below the earth's surface from the cooling magma are called intrusive or plutonic features.
    a) Concordant features: If magma positions itself parallel to the surrounding layers of rock, it is called a concordant feature.
        (1) Sill: This is a horizontal sheet of magma that has solidified between layers of sedimentary rock. The Palisades in New Jersey, along the banks of the Hudson River, provide a view of one of the best known sills. Formed during the Triassic period, this sill is hundreds of meters thick.
        (2) Laccolith (from *lac* meaning "lake" and *lithos* meaning "stone"): This feature is dome-shaped with a flat floor, and it causes overlying material to arch upward. A laccolith forms the central mass of the Henry Mountains in the Colorado Plateau.
    b) Discordant features: If igneous rock cuts across the surrounding layers of rock, it is called a discordant feature.
        (1) Dike: This is an almost vertical wall of rock that cuts across adjacent rocks. It is found that most dikes occupy cracks in the crust and are much longer than they are wide. An interesting example of dikes can be found at the West Spanish Peaks, in Colorado, where they radiate from an old volcano.
        (2) Batholith (from *batho* meaning "deep" and *lithos* meaning "stone"): This is a huge chamber of solidified magma that may extend over an area from tens to thousands of square kilometers. It is believed that the Sierra Nevada Mountains, in California, are a batholith that was uplifted and tilted millions of years ago.

(3) Stock: This is a mini-batholith that is less than 100 square kilometers (40 mi^2).

SEE ACTIVITY 4.1

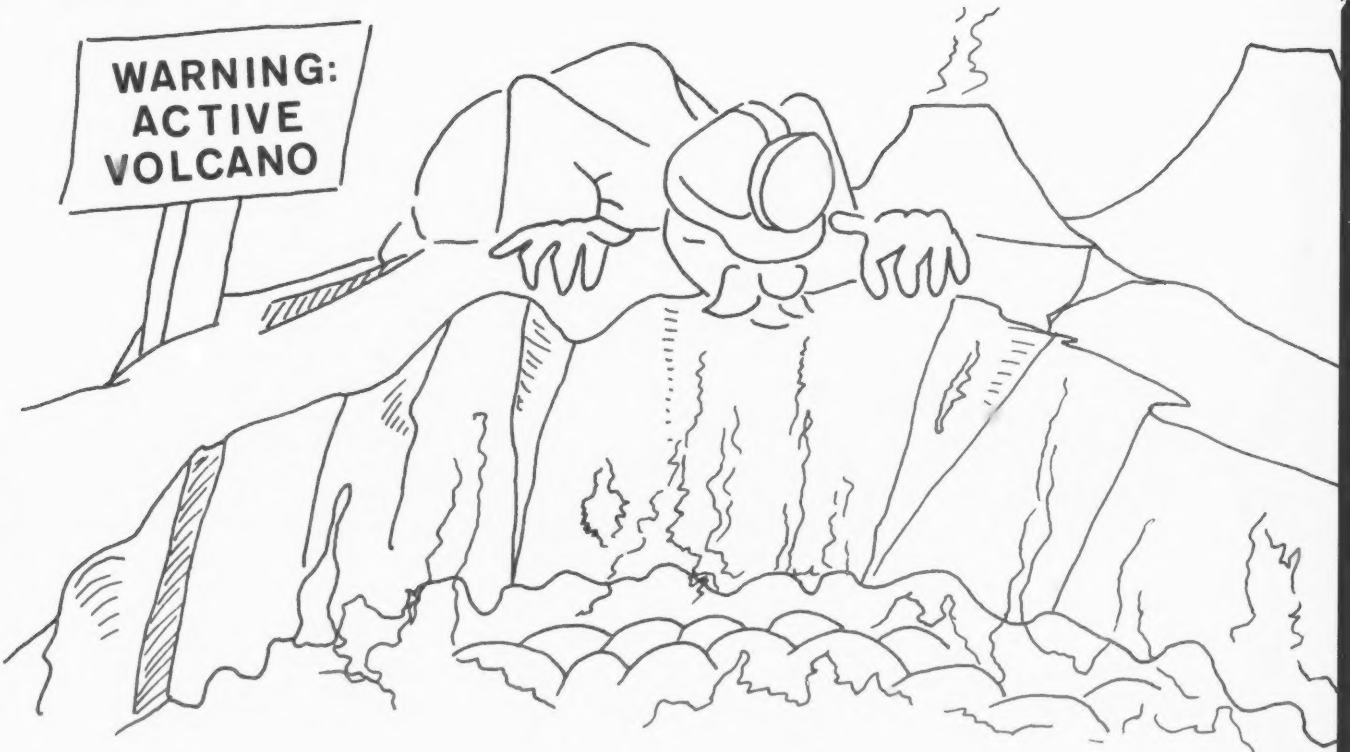
2. Extrusive or volcanic features: If magma does reach the surface of the earth, it does so by moving through a pathway of least resistance. Because of this, zones of fractured rock provide an ideal exist for magma. Those features formed by lava on the earth's surface are called extrusive or volcanic features. They include volcanic cones and will be discussed in detail in a later chapter on volcanoes. Extrusive rocks are usually composed of small crystals because they cool rapidly. Some lavas solidify so quickly that no crystals occur at all, resulting in a glassy rock such as obsidian.

B. Characteristics: There are several features that distinguish igneous rocks from the other two types of rocks.

1. Texture: Texture is the size and shape of the rock components. The rate at which the magma cools determines the size of the crystals or the texture of the igneous rock. If the magma cools slowly, individual crystals have time to form. The longer the cooling time, the larger the crystals. However, if the magma cools rapidly, the crystal size is quite small. Texture may be classed as either crystalline of noncrystalline.
   a) Aphanitic: This texture is one in which the crystals cannot be seen by the unaided eye. It results from rapid cooling.
   b) Phaneritic: Crystals are visible to the eye on a rock of this texture. They can range in size from one-half centimeter (1/5 in) to several times larger. The crystals had time to cool slowly.
   c) Phorphyritic: This texture is one of large crystals (formed by slower cooling) surrounded by a fine crystalline mass (formed by more rapid cooling). The isolated crystals are called phenocrysts. Phenocrysts grow within a fluid and have no interference from crystals growing next to them. As a result, most of them are perfect crystals.
   d) Glassy: This texture speaks for itself, it is the texture of glass. When magma reaches the earth's surface, it is then called lava. Some lavas solidify so quickly that no crystals have time to form, thus forming a glassy texture (noncrystalline).
   e) Vesicular: Resulting from the rapid expansion of volatile gases, rocks may have cavities formed by gas bubbles. As volcanic scoria is an example, one might refer to this texture as "scoriaceous." Also, as pumice is such an extreme case of vesicular texture, it is sometimes referred to as "frothy."
2. Composition: Igneous rocks differ in chemical composition. Some magmas include large amounts of silicon, sodium, and potassium but little calcium, iron, and magnesium. These magmas are felsic or acidic, and they can be recognized by their light color, their light weight, and their composition of mostly feldspar and quartz. Mafic or basic magmas are rich in calcium, iron, and magnesium, and they are recognized by their dark color and their heavy weight. They mostly contain the minerals amphibole, pyroxene, and olivine. Little or no quartz is contained, and although feldspar may be abundant, it is the dark, calcium-rich type.

C. Common examples of igneous rocks: Igneous rocks are grouped according to their being intrusive or extrusive in origin.

1. Intrusive
   a) Granite: Granite dominates the largest percentage of area in the deeper levels of large land masses. It is felsic and is composed for the most part of quartz and orthoclase. Biotite is frequently seen in samples of granite in addition to amphibole. Phenocrysts of pink potassium feldspar


WARNING:
ACTIVE
VOLCANO

IGNEOUS
ENVIRONMENTS
MAGMA

are frequently found. This coarse-grained rock is usually gray, but if there is a large quantity of potassium feldspar, it may be pink or red. Granite is used for monuments, including headstones in cemeteries, and pretentious buildings. It is very desirable as a building material because of its durability.

b) Diorite: The texture of diorite and granite is nearly the same. The difference in the two is the composition. Diorite is composed mostly of plagioclase with iron and magnesium minerals. The result is a darker color. It occurs in large intrusives and on the edges of smaller granite bodies. Diorite is occasionally used for building fronts because of its dark color. Its strength and durability make it practical for use as a building foundation.

c) Periodotite: This dark rock is widely distributed, often in pipe-like intrusions. It is composed essentially of olivine and pyroxene with no feldspar present. The magnesium and iron content is much higher than other igneous rocks, and it is considered to be mafic. It has been found that most periodotite has been so completely altered that the original minerals can be recognized only by their shapes. Most periodotites are a dull green in color and are soft and easily broken when struck with a hammer. Periodotite is not an abundant mineral in the earth's crust, but in studying the earth's dynamics, it is very important because nearly all of the earth's upper mantle is composed of periodotite. Found in dikes, sills, and laccoliths, periodotite frequently contains valuable metal ores, such as ores of platinum, chromium, and nickel. It is the primary source of diamonds in South Africa.

d) Gabbro: Although not very abundant, this dark gray, dark green, to almost black rock is composed of pyroxene and plagioclase feldspar, with some samples containing minor amounts of olivine. It is designated as a mafic rock. Gabbro is the slowly-colored equivalent of basalt.

e) Anorthosite: This coarse texture rock is found in close association with gabbro. It is composed mainly of plagioclase feldspar, but small amounts of olivine and pyroxene may be present.

f) Syenite: The name comes from the city of Syene, Egypt, where the rock was quarried in early times. This rock is light-colored and of low specific gravity. It is composed mainly of potash feldspar with minor amounts of biotite mica, hornblende, and quartz.

2. Extrusive

a) Basalt: This extrusive rock is the most abundant igneous rock and is found in almost all parts of the world. Most of the earth's crust beneath the oceans (as well as many volcanic islands) is composed of basalt. Extensive deposits of basalt have also developed on the continents as well. Basalt is composed of plagioclase feldspar, amphibole, pyroxene, and olivine. It is dark and fine-grained with a cinder-like appearance. About half of the total volume of the rock consists of small holes termed vesicles. These develop as air bubbles rise toward the top of the lava flow and are trapped in the cooling lava. This type of basalt is sometimes called scoria. In some older flows, the vesicles are filled with minerals such as native copper, as are basalts in Upper Michigan. Gabbro, which is coarser grained, is the intrusive equivalent of basalt. Basalt is used as a road material, especially in districts where limestone is not abundant.

b) Obsidian: Obsidian is a volcanic glass, breaking to give a shiny, curved surface with sharp edges. It has a chemical composition like that of granite, but being extrusive, it cooled so quickly that crystals did not have time to form. The black color results from tiny specks of scattered magnetite, while less common red obsidian is due to hematite specks.

Pumice is a glassy rock with the same mineral composition as obsidian, but it contains many small holes. Obsidian was used by our early western Indians to make arrowheads, spears, and knives. Pumice is useful as a scouring material.

c) Tuff: Compacted volcanic ash that was airborne then settled is tuff (though not as tough as big, bad Leroy Brown). Its classification is difficult, for though it is entirely of igneous origin, it is deposited as a sedimentary rock. Most of the fragments are very small, consisting of sharp, pointed, glass-like pieces. Although these fragments look like glass, they often contain small broken particles of quartz, feldspar, pumice, and solid lava. If larger particles are numerous, the rock is called volcanic breccia.

d) Rhyolite: This rock is the faster-cooling equivalent of granite. Its color ranges from light gray to pink. It is formed in highly-acidic lava flows.

e) Andesite: This rock is the faster-cooling equivalent of diorite and forms in lavas associated with volcanoes.

f) Scoria: Scoria is full of cavities formed as a result of expansion of volatile gases. Pumice has similar cavities and such a low density that it floats on water.

SEE ACTIVITY 4.2

III. Sedimentary rocks: Any rocks that are on the surface of the earth are subject to weathering. Weathering is the physical and chemical breakdown of rocks and minerals exposed to air, plants, animals, and water. For example, when water enters cracks in rocks and freezes, it expands and causes the rock to break apart. Pieces of rock, further broken down and weathered, and resulting soil that collect on the surface of the earth are continually moved by water, wind, and ice; this process is known as erosion. Eventually, erosion carries much of the weathered rock to the oceans, where it settles (or is deposited) in layers at the bottom. The loose material that settles is called sediment. If sediment consolidates, it forms rock known as sedimentary rock.

A. Clastic and nonclastic sediment: Sediment is usually considered to be any broken material either in transport or already deposited by water, wind, ice, or some mass-wasting process. A broader definition must also include matter that is precipitated from solution and deposits of organic origin.

1. Clastic: Derived from the Greek word "klastos", for "broken", clastic describes the fragmented material separated from the parent rock.

a) Pyroclastic: Pyroclastic sediment is derived from explosive eruptions of volcanoes.

b) Detrital: Detrital sediment are fragments derived primarily through weathering of parent rock. These sediments may encompass the products of chemical weathering, such as clay.

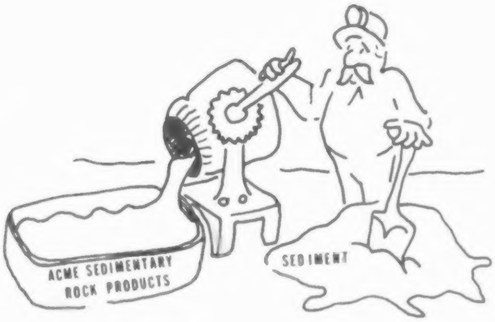
2. Nonclastic: These sediments encompass organically derived sediments and chemical precipitates.

a) Chemical precipitates: These inorganic compounds represent material precipitated from an aqueous solution. Calcite and dolomite are representative of the carbonate materials, gypsum is representative of the sulfate minerals, halite (salt) is representative of the evaporites, and silica (in the form of chert) is representative of the oxides.

b) Organically derived sediments: These hydrocarbon sediments, derived from remains of plant and animal life, form peat, lignite, bituminous coal, and crude oil.

B. Lithification: This is the process through which sediment is changed into rock. It may occur through one or a combination of the following ways.

1. Cementation: Water carries soluble material. Cementation is the process whereby this soluble material is deposited between grains of sediment binding the grains together. There are three main cementing agents.
    a) Calcium carbonate: This can be recognized by the acid test.
    b) Silica: This is usually responsible for the toughest rock.
    c) Iron oxide: This colors the rock red or yellow.
2. Compaction: This is the decrease of volume of sediment and is caused by the weight of overburden (overlying material, the stuff on top) during burial. ALso the reduced volume may be caused by compaction and squeezing out of water. Compaction is very effective with fine-grained rocks such as shale and siltstone.
3. Recrystallization: This is a process in which the crystalline material goes through a change in crystal form. Elements in earlier minerals regroup to form new crystalline compounds. As a result, an interlocking texture is formed. This process is important in producing chert and petrified wood and in changing calcium-bearing mud into limestone.



C. Characteristics: There are several features that distinguish sedimentary rocks from other types of rocks.
   1. Composition: Most sedimentary rocks are composed of minerals that are abundant in other rocks. Sedimentary rocks are not often identified on a basis of composition because there are too many factors that affect them. Commonly, sedimentary rocks are composed of quartz, calcite, clay, rock fragments, and small amounts of feldspar and mica. Sedimentary rocks are unique in that they are frequently composed of fossils.
   2. Fossils: One of the features of a sedimentary rock which reveals a great many details about the rock's history is fossils. Much can be interpreted about the environment which produced the sediments. Fossils also furnish a record of life at that time.

      Fossils represent the naturally preserved evidence of earlier life, such as skeletal remains, footprints, shells, and casts. Through preservation (being buried quickly beneath the sediment or submerged in water) fossils were protected from oxygen (oxidation) and decay. Most fossils are remains of sea life which indicate that most sedimentary strata are of marine origin.

      Rapid deposition after a volcanic explosion (ash), flowing lava (a few exceptional fossils are from rocks other than sedimentary type), stream floods, and resin balls are all examples of agents of preservation. The most dramatic example probably lies in the frozen ground (ice) preservation. Apparently the animals (mammoths) became mixed in the much of the Siberian tundra, frozen, and covered with sediments before thawing could begin again. These are sometimes found with meat and hair still intact. In the tar pits of California, remains of many mammals (even the saber-tooth cat) are preserved.

In petrification, a chemical process converts sediment into rock. Ground water deposits minerals (usually high in silica) in place of the original organic matter which is dissolved and carried away. Petrified wood sometimes retains details of the wood structure present at the time of burial.

Petrification, deep underground, can sometimes drive hydrogen and oxygen from the original organic matter. Many fossil fish are found in this almost pure carbon state.

Insects and leaves have been preserved in compacting sediments. After they were covered with sediment, the organic substances decayed, leaving behind the forms of the original organic matter.

Footprints and tracks (even raindrop impressions) have been preserved as fossil history, giving information as to size, locomotion (running, walking, hopping, etc.) and presence of toes, hoofs, claws, or pads.

3. Texture: Important clues concerning the distance the material travels and the environment in which it is deposited are provided by the texture of sedimentary rocks.
   a) Clastic: Clastic rocks are those composed of rock fragments or mineral grains (detritus) broken by weathering from any type of pre-existing rock. Clastic sedimentary rock particles are held together by cement such as calcite. (See Figure 4.1) The rock fragments found in clastic rocks may be rounded, sub-angular, or angular, depending upon the abrasion they have experienced. Angular grains are the result of transportation by ice or gravity. Rounded grains are the result of wind and water smoothing off sharp edges of the grains. That is why you find smooth, rounded pebbles in creek beds. The distance the rock fragments have traveled is also a factor that determines the grain size and rounding. If you found a large, angular boulder, you would conclude that it was not far from its source because of its large size and angular quality. Table 4.1 describes the division of clastic rocks according to the size and the sediment from which they originated.

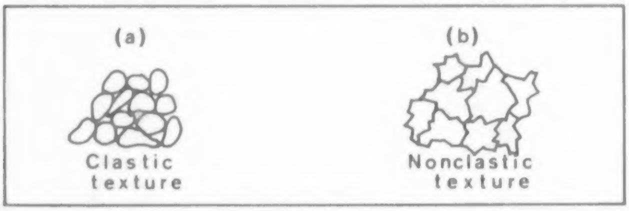


Figure 4.1. Illustrates two different kinds of texture. (a) is a texture resulting from lithified rock fragments. (b) illustrates interlocking texture developed in chemical precipitation.

Table 4.1. Clastic Rock Divisions

SIZE	SEDIMENT	ROCK
Over 2 mm	Gravel	Conglomerate (round fragments) Breccia (sharp fragments)
1/16 - 2 mm	Sand	Sandstone
1/256 - 1/16 mm	Silt	Siltstone
Less than 1/256 mm	Clay	Shale

b) Nonclastic: This texture is the result of deposition of material formed through chemical or organic reactions. Deposition is the process in which sediment is laid down. At times, minerals are precipitated or deposited, settle to the bottom of the water body, and develop into a network of interlocking crystals. (See Figure 4.1) A dense rock is created that has a crystalline texture. An oolitic texture is the result of calcium carbonate in the water accumulating around tiny shell fragments or grains of silt. Small round spheres, called oolites, accumulate and are cemented together to produce a rock that looks like a cross between a limestone and a sandstone with well-rounded grains.

4. Porosity: This is the percentage of the material that is void (has empty space). (See Figure 4.2) For example, a very porous rock is one that contains a relatively large proportion of open space, regardless of the size of the spaces. Porosity gives an indication of the ability of a rock to hold a liquid in storage. It is determined by the shape of the grains, their sorting and packing, and the degree of cementation. Sandstones and conglomerates are usually quite porous.

5. Permeability: This is the ability of a rock to transmit a liquid. It is necessary for a material to be porous if it is also to be permeable. However, the fact that a rock is porous does not necessarily mean that it is permeable. (See Figure 4.2) For example, shale contains many little cavities and is therefore very porous. The spaces are not interconnected though, so liquid cannot move freely through the shale. It is known to be impermeable. Some permeable rocks include imperfectly cemented sandstone and certain kinds of limestone in which solution has created open spaces.

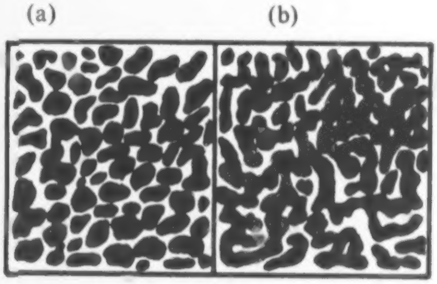


Figure 4.2. (a) illustrates porosity; the light areas represent the space through which water can travel. (b) illustrates a porous material that is not permeable.

6. Structures: One of the most characteristic features of sedimentary rocks is the stratification, the arrangements of rocks in uniform layers. Each of the individual layers is called a stratum; more than one is strata. Stratification results from the variation of any characteristics of the strata. The bedding plane is a divisional plane separating the different strata. There are a number of structures that are unique to sedimentary rocks and that are often formed on the bedding planes of strata. These structures are often important clues concerning the environment of deposition and, in some cases, the history after deposition.

a) Mud cracks: These are cracks formed on bedding planes of clay or clayey materials from the drying by the sun. They record periodic drying and sometimes suggest shallow-water environment. (See Figure 4.3)

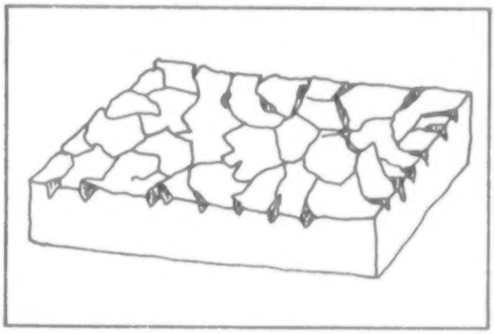


Figure 4.3. Mud cracks.

b) Ripple marks: These are wavy surfaces produced in sediment by wind, currents of water, or waves. They suggest shallow water with some current action, and they form at right angles to the current. They are also sometimes known to form in deep water. Close observation of ripple marks can show the type and direction of the current. Figure 4.4 illustrates the shape of the ripple marks formed by current as opposed to those formed by the waves.

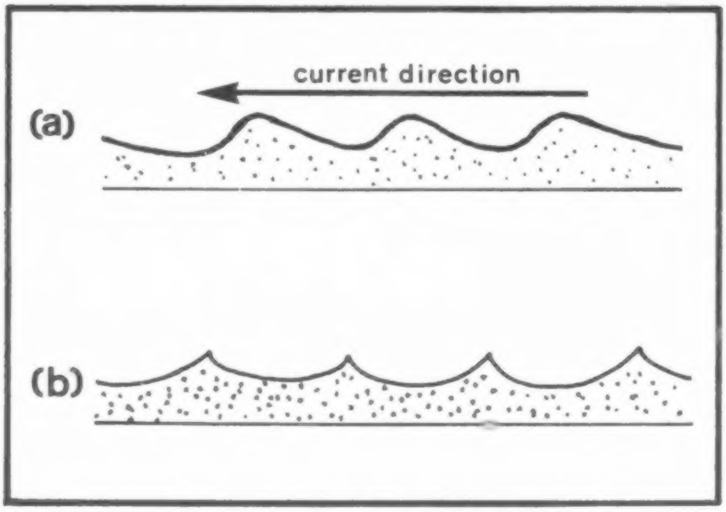


Figure 4.4. (a) illustrates current ripple marks. They do not indicate the top and bottom of beds. Turn Figure upside down and see why. (b) illustrates wave ripple marks. These indicate the top and bottom of beds.

c) Cut-and-fill: These are structures that result from the removal of a small part of a stratum. The removal is then followed by deposition of an overlying bed. Current action causes localized scouring or cutting to produce these features. (See Figure 4.5)

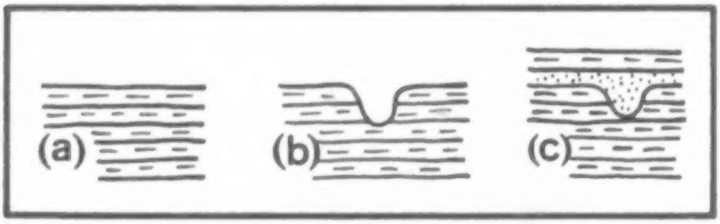


Figure 4.5. Cut-and-fill feature. (a) represents the initial bed resulting from deposition. (b) shows a portion that has been removed by current. (c) shows the feature after deposition has filled in the channel. Cut-and-fill features can be used to identify the top of strata.

d) Cross-bedding: This is strata that is on an incline (tipped) to the original horizontal surface upon which the sediment accumulated. (See Figure 4.6) It is usually produced by the deposition on the slope of a sand dune or sand wave.

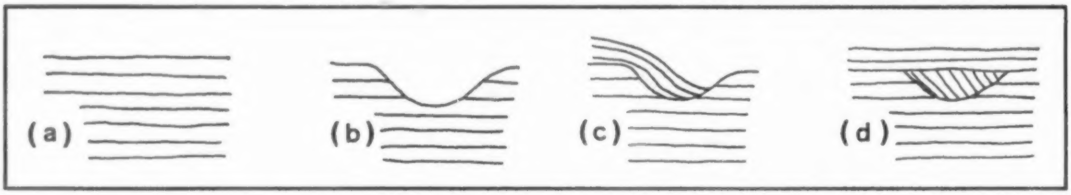


Figure 4.6. Cross-bedding development. (a) represents the original bed. (b) shows the portion of the stratum cut by current action. (c) indicates the channel being filled. (d) is the final product.

D. Sedimentary rock environments: The physical and chemical conditions under which sediments are deposited can greatly vary. As a result, sedimentary rocks differ depending upon the environment in which they were deposited. An example of this can involve the process of sorting, the size distribution among the fragments of a sediment. If a mixture of sediment is suddenly deposited in relatively still water, the larger pieces will sink faster than the smaller ones. This will produce graded bedding which means the strata varies in size from coarse near the bottom to fine near the top. (See Figure 4.7) If a situation exists in which only fragments of nearly the same size have been deposited, it is called a well-sorted sediment. Sorting and deposition can occur within a number of environments.

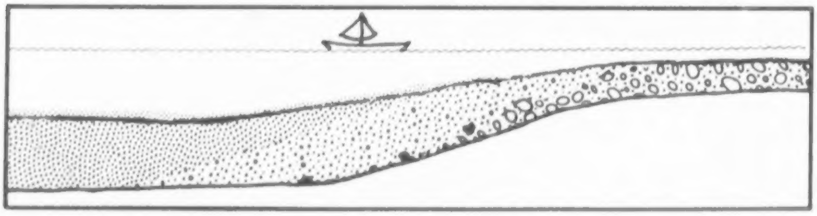


Figure 4.7. An illustration of graded bedding. The larger, heavier sediment settles first, followed by the finer material.

1. Marine environment: This environment is in a setting of oceans or marginal seas, under conditions of salt-water. It is here that most sedimentary rocks are deposited.
   a) Shallow-water: This is an area of rough water due to the nature of the waves. Medium to coarse sediment is deposited after constant agitation and reworking. Frequently, fractured shells are present. Stratification in resulting rocks is moderately well-developed. Examples of resulting rock:

      Chalk
      Conglomerate
      Coquina
      Sandstone

   b) Organic reef: This is a vertical mound of unstratified skeletal material that is both living and dead. The resulting rock is a massive, non-bedded deposit primarily composed of coral and algae, but it can contain other types. Example of resulting rock:

      Fossiliferous limestone

   c) Deep-water: The deep-water environment is a quiet one in which most sediments gently accumulate, rarely to be disturbed by the motion of water. Sea-floor types of life are abundant. The resulting rock is stratified, and it frequently has graded bedding. Because of the quiet nature of the environment, the fossils are unbroken. Examples of resulting rock:

      Shale
      Limestone
      Siltstone

2. Transitional environment: This area of rock formation is one between the land and the sea and is usually in the presence of fresh-water, with the exception of beaches.
   a) Beach: This is an area along coasts. The sediment, usually well-sorted quartz sand, is well washed by wave action. Examples of resulting rock.

      Conglomerate
      Coquina
      Sandstone

   b) Lagoon: A lagoon is a shallow body of water that may have a restricted outlet to the sea. It may have abundant organisms and accumulations of fine calcerous sand, silt, or mud. The varieties of resulting rock differ, depending upon the location of the lagoon. Examples of resulting rock:

      Fossiliferous limestone
      Sandstone
      Siltstone

   c) Delta: This is an area of large accumulations of sediment found at the mouth of a stream. Deltas are usually fan-shaped and consist of large deposits of sand, silt, and mud. The resulting rock has graded bedding, and the farther seaward, the finer-grained it becomes. Examples of resulting rock:

      Sandstone
      Siltstone

3. Continental environment: This includes all of the non-marine or land deposits.
   a) Stream (fluvial, a fancy word for work done by a stream): A stream is any water that moves across the surface of land in a channel or trough. Stream sediment ranges from poorly to moderately sorted. The sediment size varies from silt to boulder size. The deposits are in the stream valleys and are shaped in an irregular, elongate manner. The resulting rock is composed of well-rounded particles that are poorly to moderately sorted. It is poorly stratified and occasionally cross-bedded. Examples of resulting rock:

      Conglomerate   Sandstone

   b) Lake (lacustrine, a fancy word for work done by a lake): A lake is any inland standing body of water. The sediment quietly accumulates, resulting in excellent sorting. The edges of the lake may have poorly sorted sizes. The resulting rock is uniformly textured and frequently displays varves which are alternating dark and light bands or layers. These are the result of differences in the environment because of changes in the seasons. Freshwater plant and animal fossils are present. Examples of resulting rock:

      Shale   Siltstone

   c) Swamp: This is low, spongy land that is soaked with water, poorly drained, and stagnant. Fine sediment slowly accumulates, but swamps are better known for their accumulation of plant life. The resulting rock is rich in organic deposits which are evident by their dark color. Plant fossils are quite common. Examples of resulting rock:

      Coal   Shale
      Sandstone

   d) Desert (eolian, a fancy word for deposits arranged by the wind): This is an area that has little or no vegetation. Lack of vegetation makes the area vulnerable to wind action. Because the deposits are wind-blown, they are very well-sorted, fine-grained, and frequently well-rounded. Dunes, which are low, rolling, unsymmetrical hills of sand created by the wind, can form. Resulting rock is usually composed of quartz sand that is well-rounded and sorted. Cross-bedding is a well-developed, large-scale feature. Examples of resulting rock:

      Sandstone

      Another situation can exist in this environment in addition to wind deposition. Whenever an enclosed body of water is in a climate that is dry, the water evaporates quickly, making the remaining contents of dissolved solids concentrate and thereby precipitate. The resulting deposits are called evaporites. Examples of resulting rock:

      Gypsum   Rock salt (large halite deposits)

   e) Glacier: A glacier is a body of ice that is made up of recrystallized snow and is able to flow on a land surface. It is responsible for large-scale erosion and is capable of carrying any sediment, regardless of size. The sediment is angular in shape. As the glacier becomes smaller, it is responsible for two different types of deposits. Meltwater carries and deposits fine silt and sand-sized material. The glacier also simply dumps sediment, leaving mounds of unsorted debris of all sizes. The resulting rock consists of some angular and some rounded particles of mixed sizes. Example of resulting rock:

Tillite

f) Cave: A cave is a natural cavity in the ground that is usually large enough for a human to enter. Cave deposition is the result of a chemical process. Groundwater containing a weak acid trickles down through limestone above a cave and dissolves some calcite. Once the water reaches the cave, the calcite is deposited as dripstone, resulting in such features as stalactites and stalagmites. Example of resulting rock:

Travertine

4. Replacement environment: This process does not fit one specific environment, but we award it an "honorable mention" in the environment group.
   a) Petrification: When the minerals in ground water replaces decaying wood cells, petrified wood is the result. The Petrified Forest fo Arizona is an example of this process on a large scale.
   b) Substitution: Although dolostone may originate from direct precipitation from sea water, most of it probably develops by a substitution of the mineral dolomite (magnesium atoms) for calcite (calcium atoms) in limestone (ion replacement process). This seems to be the most widely accepted explanation for the great thicknesses of dolostone found.
   c) Replacement: Chert nodules are formed when calcium is replaced by silica in the form of lumps or masses in limestone (now cherty limestone). Cavities formed in limestone (dissolved calcite) may become lined with crystals formed from minerals (quartz, pyrite, and calcite) precipitated from ground water. Geodes are formed in this way.

E. Common examples of sedimentary rocks: The following rocks are divided into clastic and nonclastic texture.

1. Clastic: These, as you recall, are composed of rock fragments.
   a) Conglomerate: Conglomerates are composed of rock fragments of quartz, quartzite, or chert held together by a smaller-grained mixture of sand, clay, and cement. The coarse rock fragments are usually well-rounded and fairly well-sorted.
   b) Breccia: Breccia is similar to conglomerate, but the coarse-grained fragments are angular with little evidence of abrasion. The fragments are also poorly-sorted.
   c) Sandstone: This clastic rock comes in various colors--brown, buff, green, red, or yellow--depending upon impurities and cementing agents (calcium carbonate, iron oxide, or silica). The grains are rounded and may vary in composition but are usually quartz. Some have very little cement and are porous, readily allowing liquids to move through them and are thus permeable. Sandstone is used in large quantities for building purposes. The very pure silica-containing varieties are used as a source of quartz for pottery and glass making.
   d) Siltstone: Quartz grains, with an abundance of mica and clay minerals, make up this fine-grained, clastic rock. (Does this sound like a commercial?) When the silt particles are viewed under a microscope, they appear to be angular rather than rounded.
   e) Shale: This fine-grained sedimentary rock is made up largely of clay minerals. It is soft and has thin, distinct layers which split apart easily. About 80 percent of the exposed sedimentary rocks are shales.

They are difficult to differentiate from siltstone; there is a difference in size of particles, but it is slight. Because it is weak, shale cannot be used directly for building. However, it is an important ingredient in cement. Shale can be ground and used to make bricks, tiles, and other ceramic products used in building. Goods made from shale burn to a red color because of the iron content in the rock. "Oil shale" generally dark in color, is presently being given a great deal of attention because of the "oil crunch" we are experiencing. It may become an important source of petroleum products.

2. Nonclastic: These are the result of chemical precipitation or the presence of organic material.
   a) Limestone: At least 50 percent calcium carbonate, limestone may technically be a combination of clastic, chemical, or organic origins. It is generally fine-grained and soft, bubbling when touched by the golden finger of hydrochloric acid. It dissolves easily in water containing carbon dioxide, resulting in the common occurrence of caves in limestone regions. Limestone is represented in several forms: microcrystalline (composed of fine particles), oolitic (composed of oolites), fossiliferous (composed of fossil bits and pieces), chalk (composed of shells of microscopic organisms), and travertine (inorganically deposited as stalactites and stalagmites in caves). Limestone has many varied uses. It is used for building purposes. It is burned with shale to make cement. After chemically breaking limestone down into lime, the lime is then available for making plaster, for neutralizing acid soils, and for making mortar. Crushed limestone is used for road building and concrete making. Occasionally, it is used as a flux in the smelting of iron ores.
   b) Chert: This is a microcrystalline form of quartz that has a hardness of 7, is fine-grained, has a conchoidal fracture, and has a waxy surface when freshly exposed. Chert is not an abundant rock, but it resists chemical and physical weathering and is therefore often found. It is common as nodules (hard lumps) in other rock layers such as limestone. It was used to make early Indian weapons.
   c) Rock salt: This evaporite is not a common rock, but because it occurs in certain areas in thick beds, it is a familiar rock. It can be seen (technically) forming in salt lakes in arid regions. Can you think of any location in the United States where salt beds are now forming? (Hint: They race very fast cars there!) It is used for household and chemical purposes.
3. Organic: Plant fragments, greatly altered by bacterial action and compressed under other sediments, will eventually form a sedimentary rock of organic origin. Prolonged heat and pressure will change plants into peat, lignite, or bituminous (soft) coal. Further change into anthracite (hard) coal changes the sedimentary rock into a metamorphic rock. Coal is composed primarily of the element carbon.
   a) Environment: THe world's main sources of energy (not including the sun, the ultimate source), coal and petroleum, are referred to as fossil fuels. They are formed from once living matter which, under a special sedimentary environment, was buried and preserved. The ideal environment for coal formation is a coastal swamp where vegetation can be deposited in significant amounts to be composed by overlying sediments and undergo the necessary changes (through heat and pressure) to become a rock.
   b) Sequence of formation: In the swampy environment, dead plants accumulate, partial decomposition occurs, and peat is formed. Peat is a soft, fibrous matter, not fully compacted into the rock stage. It is sometimes used as a low-grade fossil fuel, although it burns with low heat value per mass.

Peat, under compaction by overlying sediments, eventually may be turned into a second stage of coal called lignite. This brown coal is still a low-grade fuel, slightly more heat-efficient than peat. Both peat and lignite, when exposed to the atmospheric elements, break into fragments, still retaining the woody texture of the original matter.

Further compaction changes lignite into sub-bituminous and bituminous coal. For our study, we will refer to all stages of "soft-coal" (in the sedimentary rock classification) as bituminous. The final stage in the life of coal is the metamorphic rock stage of anthracite (hard coal).

c) Types of coal: Peat and lignite do not meet the criteria expected to sedimentary rocks, therefore they will be referred to as low-grade fossil fuels. Bituminous coal is considered to be a sedimentary rock.
   (1) Bituminous: Coal composition is usually stated in terms of the proportion of fixed carbon (atoms of carbon not associated with atoms of other elements in molecules), volatiles (hydrocarbons), and water. In changing from lignite to bituminous, most of the water is removed, whereas the proportion of fixed carbon and volatiles increases by nearly 60 percent.
   (2) Anthracite: Although considered to be a metamorphic rock, reference to anthracite coal is to complete the life cycle only. In the transition from bituminous to anthracite, the volatiles are almost completely lost, leaving only the fixed carbon.

d) Summary: Coal is composed largely of carbon, hydrogen, and oxygen. During the formative stages, varying amounts of nitrogen and sulfur may be present. Coal may also contain non-organic matter which, when the coal is being used as an energy source, will remain as ash or "clinkers".

Most of the outstanding seams (layers) of coal were deposited during the Carboniferous Period (280 to 345 million years ago). It has been estimated that it would take 30 inches of peat to form 1 inch of coal.

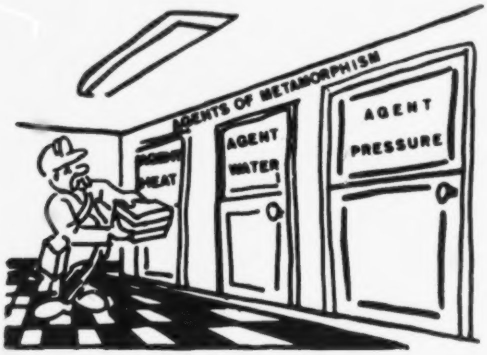
SEE ACTIVITY 4.3

PRESSURE
FLUIDS
META
MAKER

IV. Metamorphic rocks: This is a pre-existing rock that experiences a change in its texture and/or mineral composition. Rocks tend to reflect their environment, and if the environment changes, the minerals become unstable and react to form new minerals that are stable within their new environment. The altered rock changes because (1) its chemicals recombine, and new minerals form; (2) its mineral grains deform and rotate in position; or (3) its minerals recrystallize into new grains. The end result is nearly always a rock with more crystals and greater hardness. In addition, it will display new structural features that indicate it has been deformed. All three major rock types may be metamorphosed. Intrusive igneous rocks and metamorphic rocks that have already been metamorphosed are less affected because, originally, they formed in a similar environment of high temperature and pressure.

A. Agents of metamorphism: There are three factors that are responsible for metamorphism.

1. Heat: This is probably the primary agent behind metamorphism. It hastens chemical changes and is responsible for the most powerful reactions. As you would think, the deeper you go into the crust, the warmer it becomes. Knowing this, it is obvious that rocks deep below the crust are naturally going to be hot. It should be noted, however, that most metamorphic rocks form where the temperature (200° to 750°C) is greater than the average temperature at that depth.
2. Pressure: This is created by the weight of the overlying rock layers and other stresses such as lateral pressure that occur below the earth's surface. Substances that would react in a brittle manner on the surface react in a plastic manner (much like that of Silly Putty) under the influence of heat and pressure within the layers of the earth's crust.
3. Chemically-active fluids: These are liquids, primarily water aided by carbon dioxide, boric acid, hydrofluoric and hydrochloric acids, and other substances. They are important in starting chemical reactions and in providing a means to move through the rock. They may be present as a result of gases and fluids in a nearby area of magma escaping into the country rock. Fluids are present in almost every rock and only a small amount is necessary for metamorphism.



B. Texture: As with igneous and sedimentary rocks, texture is important in identifying metamorphic rocks. There are two kinds of texture.

1. Foliated: This includes any parallel structures, or mineral grains, layers that influence the tendency to easily break along planes. Foliated metamorphic rock can be recognized as closely-spaced fractures known as slaty cleavage, parallel orientation of flatter minerals known as schistosity, or bands of different minerals known as gneissic layering.

2. Non-foliated: These massive or granular rocks are commonly composed of just one mineral. Sometimes, they are recrystallized so completely that none of their original features are preserved. Other times, however, they are only slightly modified and retain most of their original features.

C. Metamorphic rock environments: Most metamorphic rocks are believed to have formed in areas of mountain building where heat and pressure are especially intense. They appear to provide evidence concerning the conditions that exist deep within the earth. Presumably, sedimentary rocks that have been deposited along the margin of a continent are buried thousands of meters deep. They then become soft or plastic. Heat, pressure, and chemically-active fluids then take action and leave their imprint upon the rocks. As the rocks are pushed up (uplifted) and eroded, metamorphic rocks that were once buried thousands of meters are exposed at the surface. There are two types of metamorphism.

Just another rock hound!

1. Contact metamorphism: This is metamorphism that occurs near the contacts of magma and solid rock. (Understand why it is called contact metamorphism?) (See Figure 4.8) High temperatures, little pressure, and chemical action are essential for contact metamorphism to occur. Its effects are influenced by the temperature of the magma, the type of pre-existing rock, the size of the intrusion, the rate of cooling, and the composition of the magma. Contact metamorphic deposits contain many mineral deposits of economic importance.

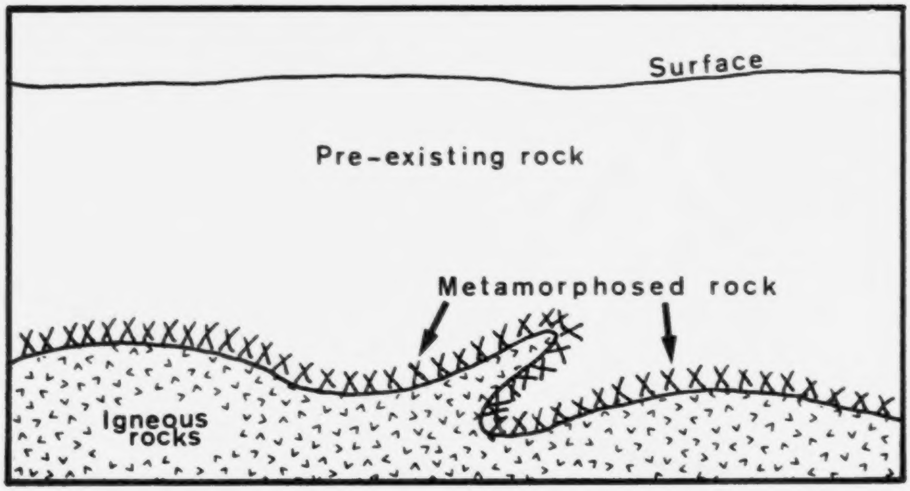

Surface
Pre-existing rock
Metamorphosed rock
Igneous rocks

Figure 4.8. An illustration of contact metamorphism. Pre-existing rock in contact with magma changes into metamorphic rock as a result of the heat and chemical-active fluids from the magma.

2. Regional metamorphism: This is the chemical adjustment of rocks over a large area under the influence of high temperature and pressure imposed on them by the depth of their burial. Under stress, the rocks usually recrystallize and are folded into mountains that are crushed, sheered, and stretched. (See Figure 4.9) This process is responsible for the greater number of metamorphic rocks.

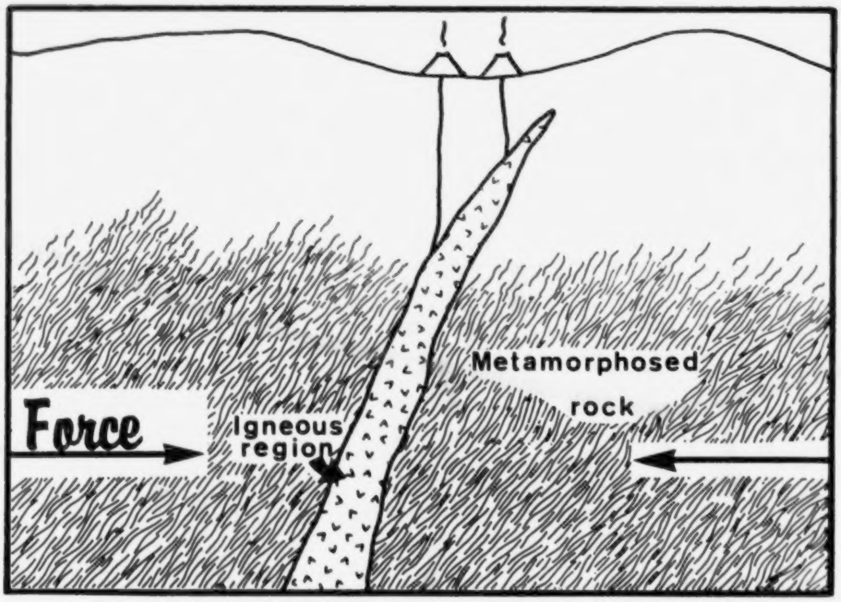

Metamorphosed rock
Force
Igneous region

Figure 4.9. An illustration of regional metamorphism with contact metamorphism and immediately surrounding the igneous region. Rocks over a large area or region are metamorphosed or changed because of heat and pressure.

D. Common examples of metamorphic rocks: The following rocks are classified accordingly into foliated and non-foliated textures.

1. Foliated: These rocks have the characteristic parallel structures and are composed of more than one mineral.
   - a) Slate: Harder than shale (its sedimentary counterpart), this dense rock is brittle and splits into sheets, thus displaying slaty cleavage. It is nonporous which makes it a good material for roofing. It is composed commonly of quartz, muscovite, and chlorite. The colors are black, gray, green, or red.
   - b) Phyllite: This rock is very similar to slate but has a satin-like luster or sheen developed on the planes of foliation. It is composed of mica, graphite, chlorite, and pyrite and is a more highly metamorphosed form of slate.
   - c) Schist: Decked with large mineral crystals that are plate-shaped, this rock is composed of muscovite, chlorite, and talc. It possesses wavy planes of schistosity. It may be formed when the metamorphism of felsite or the further metamorphism of shale.
   - d) Gneiss (pronounced NICE): Gneiss is coarse-grained and appears banded with light bands of quartz alternating with dark bands of mica and amphibole. It resembles granite in appearance and composition, except for the banding. Gneiss may be formed by extreme metamorphism of almost any rock, but common varieties are formed from granite and shale. Gneiss is sometime used for the same purposes as granite, although it is limited because the banding makes it weaker than granite.
2. Non-foliated: These massive-textured rocks are composed of only one material.
   - a) Marble: This rock is formed from the metamorphism of either limestone or dolomite. It is coarse-grained as compared to fine-grained limestone, is soft, and effervesces with hydrochloric acid. Possible colors include blue-gray, brown, pink, or white. Marble is frequently used for statues and interior decoration.
   - b) Quartzite: This metamorphosed sandstone forms one of the hardest and most resistant of common rocks. It can be distinguished from sandstone by the fact that its grains are not distinct and also by the smoothness of its fracture surface. This smoothness results from the fact that the fracture tends to split through the grains instead of around them.
   - c) Hornfels: This a hard, fine-grained rock formed by baking at contacts with magma. Commonly, it is formed from the baking of shales, so it has a composition similar to slate, but the foliation is lacking. The bedding of the shale is often preserved. If not, hornfels may be almost impossible to distinguish from basalt or felsite without a microscope.
   - d) Anthracite coal: This is bituminous coal that has been metamorphosed. It is jet black in color. It is different from bituminous coal, much harder and displaying a conchoidal fracture. For those people that like clean hands, anthracite does not soil hands as readily as bituminous coal.

SEE ACTIVITY 4.4

V. Rock Cycle: This is the sum of the processes through which earth materials are transformed in sequence from one rock type to another. There is not necessarily a specific beginning because we are dealing with a cycle. Processes include weathering, erosion, lithification, metamorphism, melting, and crystallization. One step does not necessarily need to follow another as can be seen in Figure 4.11. An example of one possible journey of an earth material through the rock cycle could involve a sand grain. At the beginning of this example, our sand grain is an ingredient of quartz in cooling magma deep below the earth's surface. With uplift and erosion, little S.G. is exposed to the big, bright world. After weathering, ice, water, and/or wind erode if from the surrounding rock and carry it elsewhere. It will stop and rest many times on its long, tiring journey, but eventually it may end up in the ocean as sediment. There, it will join its neighbors to be buried, subjected to pressure, heat, and recrystallization. Ultimately, there may again be uplift, and a similar cycle may be followed. (See Figure 4.10)

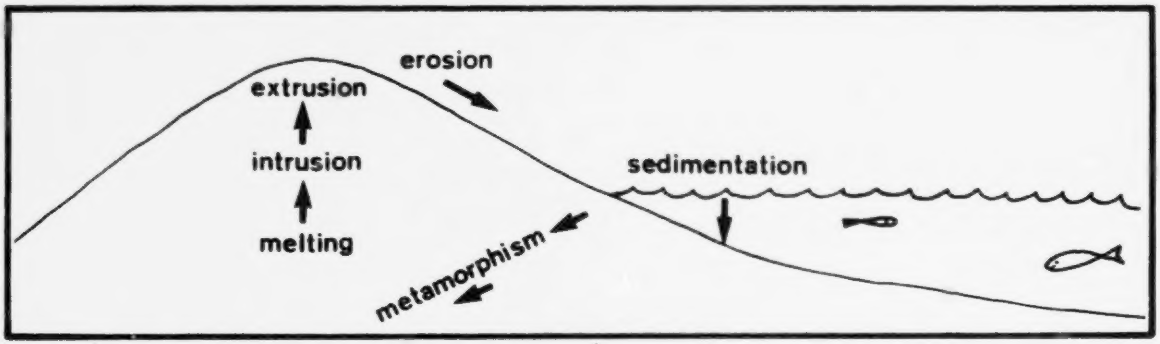
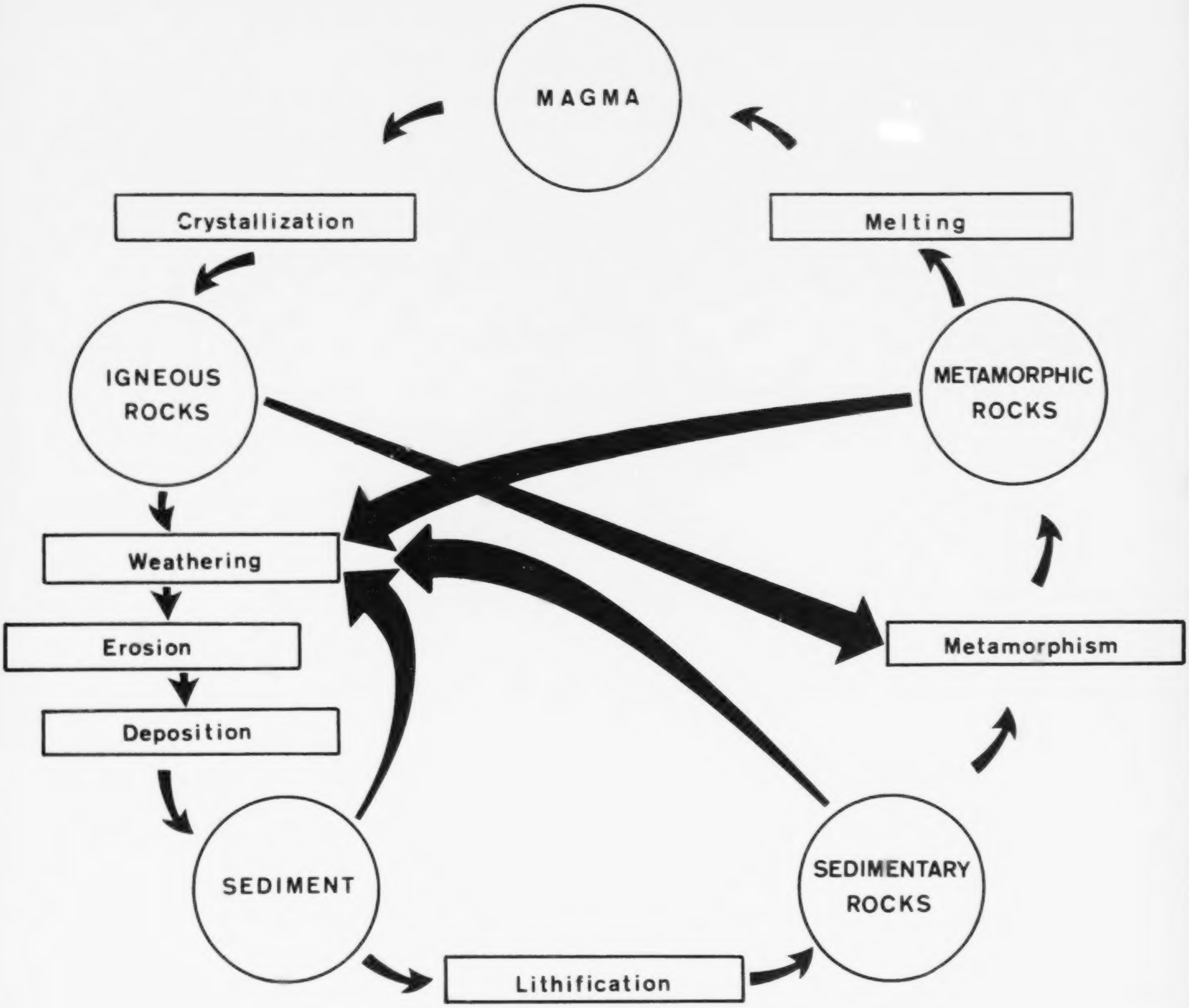

erosion
extrusion
intrusion
melting
sedimentation
metamorphism

Figure 4.10. Illustrates one possible rock cycle with the interchange of materials on the surface of the earth through the crust of the earth.

High Test
Fuel
Meta
Oil
ROCK CYCLE


MAGMA
Crystallization
Melting
IGNEOUS ROCKS
METAMORPHIC ROCKS
Weathering
Erosion
Deposition
Metamorphism
SEDIMENT
SEDIMENTARY ROCKS
Lithification

THE ROCK CYCLE

Figure 4.11. Shown are the three main groups of rocks and the processes that create them. Each rock may be derived from the other two by the processes. The arrows indicate the passage of time.

VI. Geologic time on earth: The nature of man is such that he has a basic need to organize. The secret of the earth's age and history is locked up in rocks. The key to the answers is a full knowledge of these rocks. Once the knowledge is acquired, it can be organized. One form of organization is a geologic time scale--a broad division of time that divides the earth's history.

A. Historical background of the geologic time scale: The modern geologic time scale began to develop in the nineteenth century, in Europe. It was discovered that certain horizontal rock layers contained fossils unlike those in other horizontal rock layers. By using these key or index fossils as markets, rocks of the same age could be identified and correlated throughout the world. (Correlation is when rocks in two or more different areas are determined to be equal in geologic age and position.) (See Figure 4.12) Eventually, geologists were able to reconstruct the various events that shaped the earth's surface. These events, such as mountain building, comprise units of geologic time. Geologists divided the earth's history into three divisions: eras which are broad spans of time based on the general character of life that existed during these times, periods which are shorter spans of time based partly on evidence of major disturbances of the earth's crust, and epochs which are subdivisions of periods.

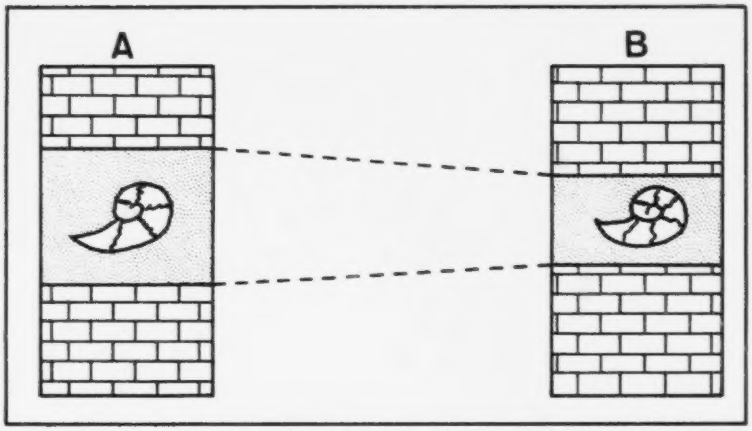


Figure 4.12. A and B present the correlation of columns of rock in two different locations. The middle layers of rock can be identified as the same rock layers because the fossil found in both is unique to that layer.

B. Relative time scale: When geologists first devised the geologic time scale, the scale was based upon the relationship of one rock to another or relative time (the sequence of geologic events that happen in time). The relative ages of rock units were based upon several simple laws, two of which are: (1) the law of superposition stating that in undisturbed rocks, the oldest rocks are on the bottom and the youngest on top, and (2) the law of original horizontality stating that all rocks are deposited horizontally. For example, when examining a rock unit, the laws mentioned above are applied, and the relative age of the rock is given as younger than the rocks below it and older than the rocks above it. Thus, the relative time of rock formation, or the relative age, is established. (See Figure 4.13)

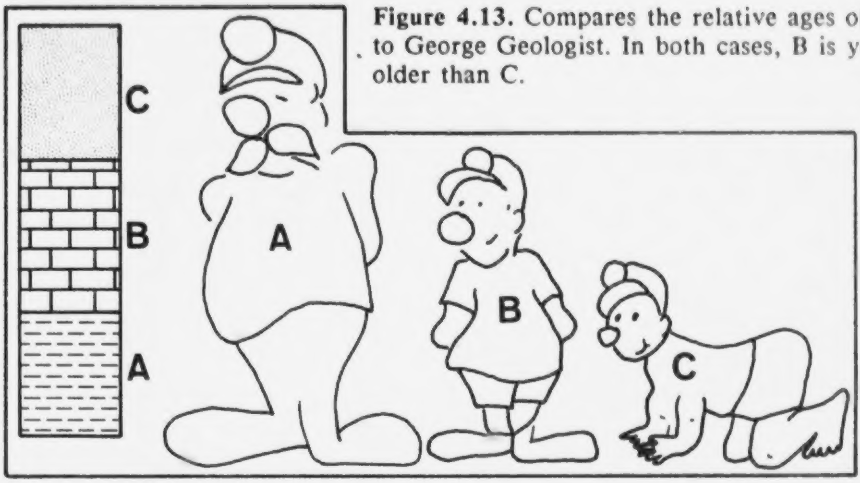


Figure 4.13. Compares the relative ages of a column of rock to George Geologist. In both cases, B is younger than A and older than C.

C. Absolute time scale: This is an alternative to relative time, and it is based on units of time stated with numbers. For instance, the absolute time of a specific rock unit is 19,000 years old. The determination of absolute time was not possible until the discovery of radioactive dating. This involves the following: "A chemical element consists of atoms with a specific number of protons in their nuclei but different atomic weights owing to variations in the number of neutrons. Atoms of the same element with differing atomic weights are called *isotopes*. Radioactive decay is a spontaneous process in which an isotope (the parent) loses particles from its nucleus to form an isotope of a new element (the daughter). The rate of decay is conveniently expressed in terms of an isotope's *half-life*, or the time it takes for one-half of the nuclei in a sample to decay. Most radioactive isotopes have rapid rates of decay (that is, short half-lives) and lose their radioactivity within a few days or years. Some isotopes, however, decay slowly and several of these are used as atomic clocks."* (See Figure 4.14) Absolute time is quite compatible with relative time. When absolute dates becomes available, they are simply incorporated within the sequence of relative dates. *Source: "Geologic Time," USGS pamphlet.

D. Geologic time scale: The geologic time scale in use today combines relative and absolute time. It is arranged, in chronological order with the oldest time at the bottom, progressing to the youngest at the top. (See Table 4.2) The time scale in this book includes the names (and their origin) of every era, period, and epoch, and some of the physical and biological occurrences during the different times.

SEE ACTIVITY 4.5

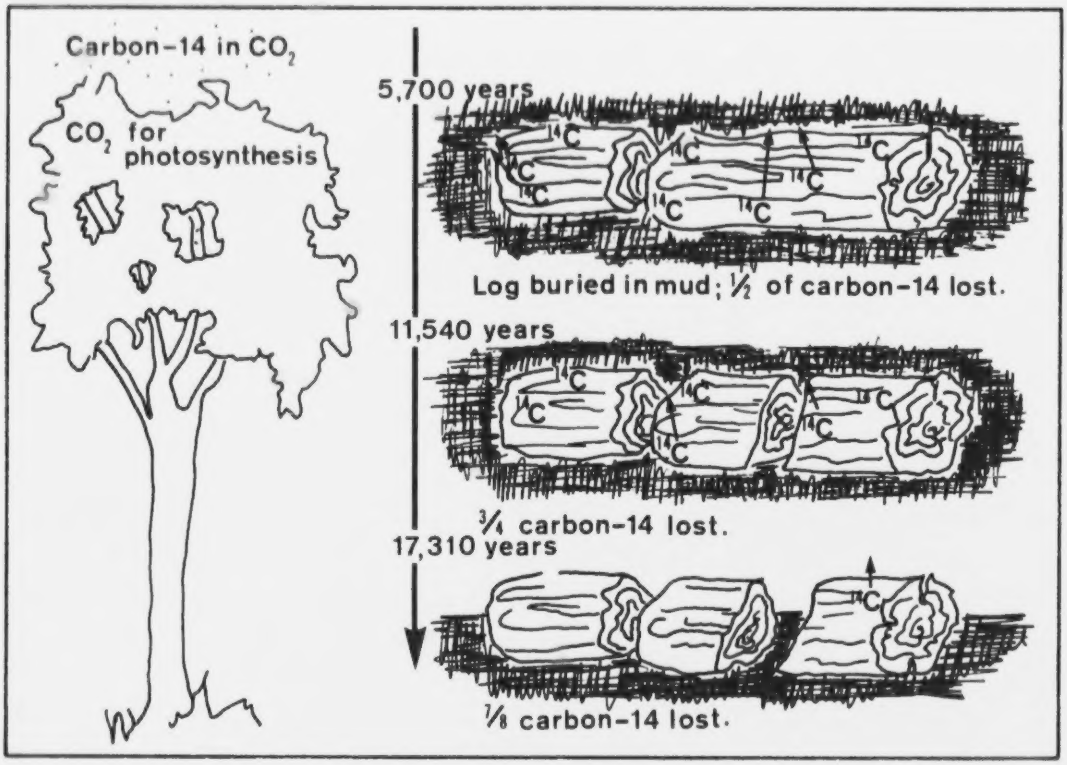

Carbon-14 in CO_2
CO_2 for photosynthesis
5,700 years
^{14}C
Log buried in mud; ½ of carbon-14 lost.
11,540 years
¾ carbon-14 lost.
17,310 years
⅞ carbon-14 lost.

Figure 4.14. An example of dating the age of a sample of wood by measuring the amount of the isotope carbon-14. Shown in sequence of formation, carbon-14 is in the carbon dioxide in the air. The CO2 is breathed in by a tree, to be used in photosynthesis. After death of the tree, it becomes buried, and the amount of carbon-14 decreases through radioactive decay. By measuring the remaining carbon-14, the time of death can be determined.

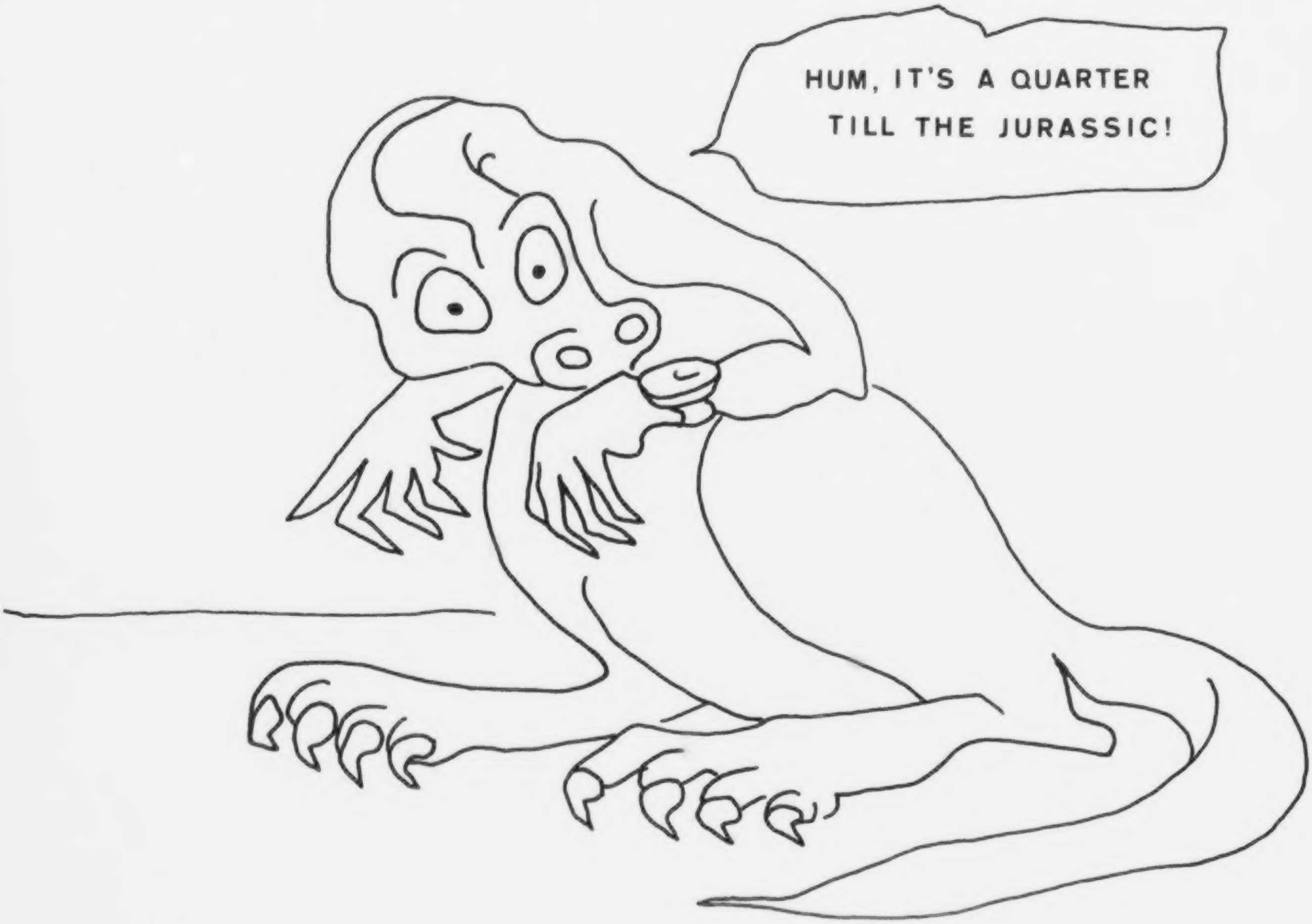

HUM, IT'S A QUARTER TILL THE JURASSIC!

Table 4.2 Geologic Time Scale

ERA	PERIOD	EPOCH	ORIGIN OF NAMES	HISTORY OF LIFE	IMPORTANT GEOLOGIC EVENTS
CENOZOIC (Age of Recent Life)	QUATERNARY	Recent (Holocene) (10,000)		Man dominant. Domestic animals develop.	Widespread glaciation. Great Lakes form.
		Pleistocene (2,000,000)	From Greek meaning less recent; epoch has 20-40% modern species.	Early man. Elephants flourish in North America then die out.	Widespread glaciation.
	TERTIARY	Pliocene (11,000,000)	Tertiary names indicate the degree of relationship of fossil molluscs to those still alive. Pliocene means more recent, with 50-90% modern species. Miocene means less recent, 20-40%	Modern horse, camel, and elephant develop.	Major uplift of Rockies. Baja, Cal. separates from mainland, forming Gulf of California.
		Miocene (25,000,000)		Spread and development of grazing mammals. Horse migrates to Asia.	Mediterranean dries up. Growth of Himalayas. Red Sea opens. Africa moves up to create Alps.
		Oligocene (40,000,000)	From Greek meaning little recent with 10-15% modern species.	Earliest elephants. Monkeys die in North America.	Main Pacific Plate touches North America altering mountain formation in western U.S.
		Eocene (60,000,000)	From Greek meaning dawn, with 1-5% modern species.	First rhinoceroses and camels. Ancestors of modern horse.	Volcanoes in western U.S. Australia separates from Antarctica. India begins to ram Asia.
		Paleocene (70,000,000)	From Greek meaning ancient, with 0% modern species.	First primates and horses. New mammals develop.	Land bridge between Americas submerges. Rockies continue to develop from Cretaceous.
MESOZOIC (Age of Medieval Life)	CRETACEOUS (135,000,000)		From Latin word for chalk (creta) composing white cliffs along English Channel.	First flowering plants. Extinction of dinosaurs.	North America and Europe separate. India breaks from Australia and Antarctica. Andes form.
	JURASSIC (180,000,000)		Named for Jura Alps where these rocks were first studied.	Dinosaurs at their peak. First birds. More mammals.	North America and Africa move apart. Sierra Nevada batholiths forming.
	TRIASSIC (225,000,000)		From word "trias" indicating the three-fold character of these rocks in Europe.	First mammals. Reptiles thrive.	Ocean between Europe and Asia closes. Urals begin to form.
PALEOZOIC (Age of Ancient Life)	PERMIAN (270,000,000)		Named for ancient state of Permia, Russia where these rocks were first studied.	Mammal-like reptiles.	Ancient Atlantic Ocean completely closes. Pangaea formed.
	PENNSYLVANIAN (LATE CARBONIFEROUS) (305,000,000)		Named for the coal-rich rocks found in the state of Pennsylvania.	Spread of "coal" plants. Large insects.	Coal swamps in many parts of North America and Europe. Appalachians complete uplift.
	MISSISSIPPIAN (EARLY CARBONIFEROUS) (350,000,000)		Named for the Mississippi River valley where these rocks are well exposed.	Earliest reptiles. Forests of coal producing plants.	Widespread seas in North America. Mountains begin in southern North America.
	DEVONIAN (400,000,000)		Named for Devonshire county in England where these rocks were first studied.	Amphibians seek land. Fullest development of fishes.	Mountain building in New England and Canada. Interior of North America submerges.
	SILURIAN (440,000,000)		Named for Silures tribe of ancient Wales during Roman conquest.	First air-breathing animals. First land plants.	Salt and gypsum deserts in eastern U.S.
	ORDOVICIAN (500,000,000)		Named for Ordovices tribe of ancient Wales during Roman conquest.	First vertebrates (fish). Trilobites at peak development.	Ancient Atlantic Ocean begins to shrink. Over 60% of North America covered by seas.
	CAMBRIAN (600,000,000)		From Roman name for Wales (Cambria) where complex fossils were first studied.	First abundant animal fossils.	Sediment deposited in inland seas.
PRECAMBRIAN (4,500,000,000)			Name meaning all time before Cambrian.	Earliest plants. Marine invertebrates, a few with shells.	Complex igneous and metamorphic activity. Oldest dated rocks. Glaciation, probably worldwide.

Numbers refer to time in years since the beginning of the era, period, or epoch.

You will be responsible for the names of the eras, periods, and epochs.

VII. Summary: In the story of the earth, the evolution of rocks involves an unending cycle much like that of a merry-go-round. Magma crystallizes into igneous rock. With exposure at the earth's surface, processes can deliver the destroyed igneous rock to a body of water as sediment. With lithification, sedimentary rock is created. Sedimentary, igneous, or even metamorphic rock may be in such a situation as to be exposed to heat, pressure, and/or chemically-active fluids, yielding metamorphic rock. The rock cycle describes the possible interactions of the different rock types, and much depends upon the "fickle finger of fate" as to which particular path a rock may follow.

Graduates of petrology: You should now know when to call a rock a rock and when to call an alleged rock a mineral!

I am going to give up rock collecting. It is too much trouble pasting them in my scrapbook.
GLUE

Chapter 4: Problems and Questions

1. Think about all the rock types (getting a headache?). List three (3) characteristics that all rock types have in common. Next, list two (2) charcteristics that are different for each type.
2. Briefly (without using a diagram) describe the steps in the rock cycle.
3. Explain how contact and regional metamorphism differ.
4. Discuss the relationship between crystal size and cooling rates in igneous rocks.
5. What is meant by the "sorting" of sediment?
6. Why are marbles and quartzites rarely foliated?
7. What kind of rocks would you expect to find in your home area? Explain why.
8. Explain how you could distinguish a conglomerate from a breccia; also explain how their environments differ.
9. Discuss the causes of each of the igneous rock textures.
10. Given the following rock exposures, briefly describe the area's past geologic history:
    (a) A mountain of granite
    (b) Layers of sandstone, shale, and limestone
    (c) A quartzite canyon
    (d) A cliff with rhyolite at the bottom, limestone above, and a basalt dike cutting both layers
11. Compare and contrast the processes of lithification and crystallization.
12. Why is it important to have a geologic time scale?
13. Compare and contrast relative geologic time with absolute geologic time.

Unit II: Earth Materials

CHAPTER 5: Mineral Resources

- I. Introduction
  - A. Mineral
  - B. Mineral Deposit
  - C. Mineral Reserve
  - D. Crude Ore
  - E. Mining
  - F. Milling

- II. Mineral Resource-forming Environments

- III. Mining
  - A. Exploration and Discovery
    - 1. Old Methods
    - 2. Newer Methods
    - 3. Today's Methods
    - 4. The Future
  - B. Extraction
    - 1. Surface Mining
      - a) Open-pit Mining
      - b) Quarrying
      - c) Strip Mining
      - d) Placer Mining
    - 2. Underground Mining
      - a) Stoping Method
      - b) Room and Pillar Method
      - c) Long-wall Method
      - d) Caving Method
    - 3. Pumping
      - a) Oil and Gas Accumulations
      - b) Production Techniques
      - c) Secondary Recovery
    - 4. Surprise Discoveries

- IV. Milling
  - A. Flotation
  - B. Gravity Separation
  - C. Magnetic Separation
  - D. Solution and Precipitation
  - E. Smelting and Refining
    - 1. Mineral Separation
    - 2. Beneficiation
    - 3. Coal Gasification and Liquefaction
    - 4. New Techniques
      - a) Fluid-bed Combustion
      - b) MHD (Magneto-hydro-dynamic) Generator

- V. Environmental Effects
  - A. Sediment
  - B. Water Pollution
  - C. Air Pollution
  - D. The Future

- VI. Influence of Mineral Resources on Man's History
  - A. Early Man
  - B. Stone Age
  - C. Copper and Bronze Age
  - D. Iron Age
  - E. Steel Age
  - F. Observations

- VII. Cycle of Mineral Production
  - A. Exploration and Discovery
  - B. Amalgamation and Consolidation
  - C. Industrial Integration
  - D. Rapid Depletion of Cheap Domestic Raw Materials

- VIII. History of Mineral Resources in the United States
  - A. Early History
    - 1. Indians
    - 2. European
    - 3. Colonists
  - B. Expansion and Mechanization
    - 1. Economic Developments
    - 2. Opening the West
    - 3. Civil War
  - C. Industrial Period
    - 1. Post Civil War
    - 2. Westward Rush
    - 3. Conservation
  - D. Twentieth Century
    - 1. World War I
    - 2. Post World War I
    - 3. World War II
    - 4. Post World War II
    - 5. Energy crisis
    - 6. Present

- IX. Earth's Energy Sources
  - A. Coal
  - B. Oil and Gas
  - C. Oil Shale
  - D. Nuclear Energy
  - E. Solar Energy
  - F. Water Power
  - G. Geothermal Energy
  - H. Wind Power
  - I. Tidal Power

- X. Summary

Related Activities

Vocabulary

Review mineral-forming environments.

Forecast future and relate that future to role of mineral resources.

Problems and questions

Mineral Resources Geo Facts

It has been found that Siberia may contain uncounted material resources that could have a large effect on the world's economy. Despite earthquakes, mudslides, isolation, and extremes in climate, prospectors and geologists are exploring the area which may have the largest oil and gas reserves in the world. In addition, there are gold, coal, iron ore, and a variety of non-ferrous and precious metals.

Since the birth of Jesus, half of the energy that people have consumed has been consumed within the last century. In dealing with metals, people have mined as much in the last 60 years as was mined during the first six million years of our existence on earth.

At the end of World War I, 50 of the 92 naturally occurring elements were used. Now, there is a potential use for all of them.

From a ton of coal, we can get numerous products: burned directly, we get heat; roasted coal gives coke which can be burned or used in various chemical processing or manufacturing operations; gases given off may be converted into 8 to 10 gallons of coal tar, a smaller amount of light oil, several pounds of ammonia, and 290 cubic meters (10,000 ft^3) of "coal gas."

Each year, over 3.5 tons of stone, sand, and gravel per person in our country must be dug from the earth.

Every year, over 500 pounds of clay, over 200 pounds of common salt, and over 100 pounds of phosphate rock are used by each of us, directly or indirectly.

To support a single person in our society, altogether, over 20 tons of raw materials must be dug from the earth and processed each year.

In the next ten years, more aluminum, oil, and other mineral resources will be used than have been used since the beginning of time.

Chapter 5: Word List

Resourceful Terms

Caving
Crude ore
Milling
Mine
Mineral
Mineral deposit
Mineral reserve
Mineral resource
Mining
Open-pit mining
Overburden
Placer mining
Quarrying
Reclamation
Room and pillar mining
Secondary recovery
Shaft
Smelting
Stope
Stoping
Strip mining
Surface mining
Tailings
Underground mining

Straight Terms

Adhere
Amalgamation
Barter
Consolidation
Depletion
Excavation
Flux
Froth
Integration
Ironclad
Material
Mechanization
Munitions
Pharmaceutical
Prolific
Reserve
Resource
Self-sufficient

ILL
COAL
I want to say that I'm sorry for the insulting things I said about you!
Needs for energy

UNIT II: EARTH MATERIALS

Chapter 5: Mineral Resources

I. Introduction: Mineral resources are the quantities of minerals that are known to exist, are assumed to exist, or that are even undiscovered at present. Because they are a resource, they have value to man. If you stop to think about it, the role that mineral resources has played in your life is monumental since the moment you were born. And, it is because of this important role that mineral resources plays in your life that it is important to study them. Not only do they influence your life, but they also affect the strength of nations possessing them. For instance, the differences between an industrialized country and a non-industrialized country can be directly related to the mineral resources each country has available. However, before going into any discussion, it is necessary for you to understand common mineral resource terms.

A. Mineral: In the mineral chapter, a mineral was defined as a natural, inorganic element or compound that has a definite internal structure and specific chemical and physical properties. This definition will be expanded in this chapter to include all non-living substances of the earth. In this way, materials such as fossil fuels (oil, for example) and rocks (gravel, for example) can be included.

B. Mineral deposit: This is a naturally occurring concentration of both metallic and nonmetallic minerals and/or rocks that can be mined for commercial purposes (sold at a profit).

C. Mineral reserve: This is a party of mineral resources; it consists of the deposits which are known to exist and can be produced with present technology and under current economic conditions. A mineral resource is the known reserves plus possible reserves (those that eventually may become available).

D. Crude oil: This is a mineral deposit containing a profitable metal plus any unprofitable metal or nonmetal. Economic considerations are important in determining whether or not the ore is worth mining. If the mining or milling expenses exceed the profit, it is certainly not worth mining or milling.

E. Mining: Process of extracting mineral resources from the earth.

F. Milling:This is the process of separating the valuable mineral from the waste material with which it is associated.

II. Mineral resource-forming environments: In the previous chapters, the geologic mineral and rock-forming environments were discussed. By knowing how various materials and rocks form and by knowing the geology of various parts of the earth, those in search of mineral resources are aided in their discovery. For example, this insight aided early gold miners. Even with their limited knowledge of geology, they knew that granite and gold were associated, so in search of gold, they often looked first for granite. More sophisticated procedures are used today but not without that basic knowledge of formative environments.

SEE ACTIVITY 5.1

III. Mining: Mining is the process of extracting matter from a medium. For the extraction of minerals or rocks, an excavation is dug. For the extraction of liquids or solids which may be converted to liquids, a hole is drilled and some pumping technique is used. There are many techniques used in existing minerals.

A. Exploration and discovery: Some minerals are found by chance, but most are found through a thorough investigation of existing data, collection of new data, testing, and analysis (and a whole lot of luck thrown in).

1. Old methods: In the early days, blind luck played an important role in the discovery of minerals. By chance, a few early prospectors (a mule, a plug of tobacco, and a can of beans made you a prospector) saw glitter in the rocks that turned out to be valuable "strikes". But, the old theme for many who approached mining in such a hit-and-miss fashion. Much of the early exploration for petroleum amounted to direct observations of oil seeps and oil-polluted waters and then determining where to drill wells to reach the source of the oil.

Even today, armed with very little more than great intestinal fortitude a few still rely on their instinct, and luck. Take the case of "Dad" Joiner. As a 70-year-old dreamer and a failure in several other "wildcat" drillings, operating on borrowed money, drilling where the experts were almost certain that there was no oil, and using a converted sawmill boiler for power and old tires and wood for fuel, he hit "black gold" near Kilgore, Texas. This strike was the beginning of the East Texas field, one of the largest deposits of petroleum ever discovered. It has been said that if "Dad" Joiner had drilled a quarter of a mile east of his discovery well, he would have again failed. Luck?

2. Newer methods: Armed with the same resources as his predecessor, but with a working knowledge of mineral formation, structural make-up of mineral-containing rocks, and some basic geophysical data, the prospector of this period ventured into the field (with his hammer, hand levels, and Brunton compass) to conduct research involving surface and subsurface mapping of sedimentary rock layers. After surveys were completed, samples were taken, and data were analyzed (and if positive results were realized), mining (or drilling) commenced. Although this method was not infallible, it took much of the guess-work out of the exploration and discovery processes.
3. Today's method: Mining exploration and discovery have entered a high-technology, high-cost arena. The use of high-resolution remote sensing photographs, taken from high-flying aircraft and satellites, are proving to be a most interesting and accurate mode of exploration.

   Exploration sometimes involves measurement of magnetic intensity, density, and electric resistivity. Seismic testing has reached a high level of sophistication. Deep drilling techniques have been perfected. But even now, there still remains a distinct chance of error in predicting the location of economic minerals (most geologist still carry a rabbit's foot).
4. The future: Combining the principles of geology with physics (gravity, magnetic attraction, sound, and electrical currents), geophysicists are now able to analyze data collected by airborne magnetometers, vibrator trucks (ground thumpers to produce seismic waves), sleeve exploders (generator of sound waves in deep-sea tests), and satellite imagery. With the introduction of magnetic tape, the computer can now process the vast amount of data, being accumulated by seismic activity.

   In correlating this data with maps of the surface and subsurface structures, petroleum geologists are better able to predict where oil is likely to be found. Where will our next "Prudhoe Bay" strike be located? Will it be in one of the many dozens of sedimentary basins already identified but tested only to a depth of 2 miles or less? Is there petroleum at a greater depth? With new alloys for drill pipe and new drill bits capable of withstanding the heat of deep-test drilling, the drillers take their rigs back to the sedimentary structures which have already produced billions of barrels but are currently producing little? The Williston Basin (Montana and the Dakotas) shows what can happen. This basin was a great producer during the 1950's and 1960's, but it began to fade in the early 1970's. In 1976, deep-drilling opened the field again with production of new oil reaching nearly 1 billion barrels.

   Or we will continue to drill farther offshore? Being much more expensive than on-shore drilling, to what distance off-shore and to what depths can drilling take place and still be economically viable? The hostile environment (sea ice or storms) of deeper waters pose another problem for off-shore drilling crews. New design in structures to support drilling has helped drillers to combat deep water problems.

   Or, if all these options fail to produce the required needs for petroleum, will we tackle the very complex rock strata of the Rocky Mountain range where seismic data defies analysis? Or will we, by some marvel in technology, be able to extract economically the great reserves of oil locked in oil shales (estimated to be more than 2 trillion barrels in the U.S. alone)? It has been a long way from Colonel Drake and Titusville, Pennsylvania, hasn't it?

B. Extraction: After finding a mineral deposit, it is necessary to determine the best method to mine it. The early methods were usually uncomplicated, and attempts were made to mine just the pure forms of the deposits, such as pan-mining for gold, which required little technology. Early coal mining could involve locating a seam of coal in an outcrop and digging into the seam as far as was possible. In this way, overlying rock (unless it fell on the miner!). Hard rock was mined underground by first building a fire next to the mine wall, thereby heating the rock. Next, water or vinegar was thrown on the wall causing the rock to break much the same way that cold water poured into a hot glass causes the glass to break. Today, there are basically two approaches to mining mineral resources: remove the resource from the top of the ground or go below the ground to mine it.

1. Surface mining: This is any type of mining in which the mineral resource is in some way exposed to the surface of the earth from where it is then mined.
   a) Open-pit mining: This type of mining consists of large excavations that are open to the sky. Metals such as copper and iron ore are frequently mined in this manner. Overburden, all of the earth and rock above the mineral deposit, is removed and placed in a nearby sea, thus exposing the deposit. (See Figure 5.1) The removal of the deposit usually begins near its center and works outward from the surface downward, creating a series of benches. The deposit is loosened and removed by truck or rail transportation. When the deposit is completely removed, the law states that the overburden is to be returned to its original location, and the site is to resemble its original state as much as possible. (In practice, this step has been frequently disregarded.) This process is known as reclamation. If an ore body is close to the surface, it is usually cheaper to remove the overburden. A rule of thumb is to use open-pit mining if the total waste removed is less than three times the amount of ore. Because of this restriction, mining is usually less than 304.88 meters (1,000 ft) in depth. In addition to being cheaper than underground mining, open-pit mining is also safer, and larger amounts of material can be moved in a day.

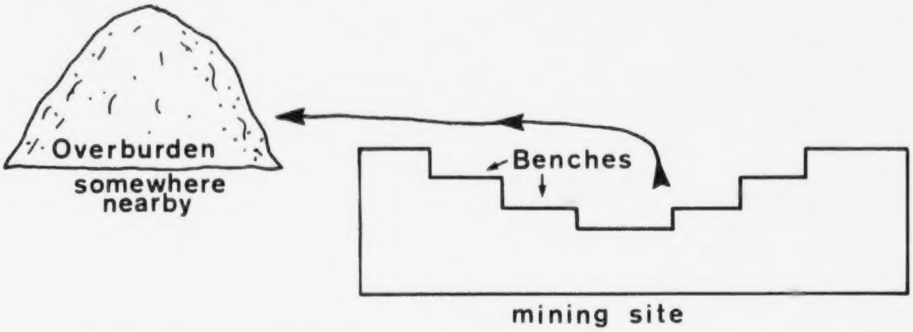


Figure 5.1. An illustration of an open-pit mine with associated benches and the inevitable pile of overburden.

   b) Quarrying: A special type of open-pit mining is called quarrying. The process is the same as described for open-pit mining. The term, however, has limited the extraction of mineral resources used for construction materials (sand and gravel) or as building stone (granite, limestone, marble, etc.).
   c) Strip mining: Strip mining is the removal of nearly horizontal layers of mineral resources such as coal. As with open-pit mining, the overburden is removed and set aside, the mineral is dug out, and, presumably, the overburden is replaced so as to resemble its original state. Strip mining is used when the overburden is 22 meters (75 ft) thick or less.

d) Placer mining: Streams tend to sort out and separate materials they carry (load) according to size and density. Materials of high density (gold) are deposited in concentrated masses within the gravel and sand deposits and are called placer deposits. The process of extracting these high density minerals from the sand and gravel is called placer mining. The most familiar method is the gold pan method (the old prospector in an old creek bed) in which heavier metals are worked to the bottom of the pan and the lighter rocks are discarded. Even today, this method hangs on. You may, for a price, try your hand at this in various amusement centers in the United States.

Placer mining today is done on a much larger scale. Huge amounts of gravel and sand are scooped up by dredges and washed, separating the riches from the waste. A form of hydraulic mining has been operative since the turn of the century. In this, very powerful jets of water wash the sands and gravel into a sluice where gold (if any) is collected from the waste material. Gold, platinum, cassiterite (tin) and diamonds form important placer deposits around the world.

2. Underground mining: Underground mining is necessary when the mineral deposit is buried deep in the ground. Because of the higher cost of underground mining, the deposit must consist of a high-grade mineral. This type of mine includes an inclined, vertical, or horizontal passageway, the shaft, that is dug to the level of the deposit and is used to enter the mine. Spreading out from the shaft is a honeycomb network of horizontal tunnels. There are several methods of mining the deposit once there is access to it, and the method depends upon the size and shape of that deposit.

a) Stoping method: This is a system of mining an irregularly-shaped mass of ore, leaving an opening (stope) from which ore is extracted. The stope can be above the horizontal passageway or below it. (See Figure 5.2)

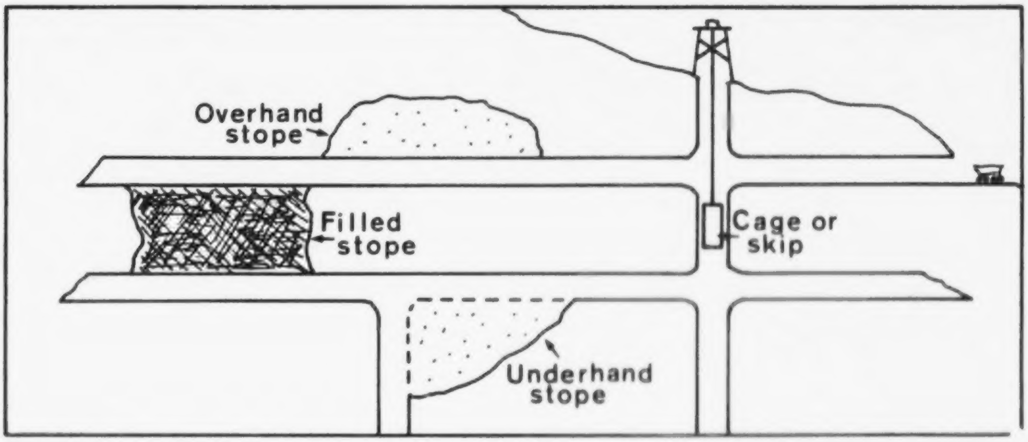


Figure 5.2. Cross-section of an underground mine. The dotted areas are stopes. The solid area has had the ore removed and has been filled in with gob (nonvaluable materials).

b) Room and pillar method: If the deposit is flat-lying, this method is used. The mineral resource is removed along the horizontal passageway creating a large room. Pillars of unbroken rocks are left in place to support the roof.

c) Long-wall method: This method is also known as long-face method. It provides for the removal of a greater percentage of the coal than does the room and pillar method. Movable props support the mine roof in the vicinity of the face of the coal being extracted. Sometimes a face is nearly the length of a football field. As the coal is mined, the roof supports are advanced, allowing the roof to fall, or subside, into the mined-out area.

Sometimes the face of the coal seam is along a circumference of a large circle surrounding the shaft of the mine. Mining advances inward from the starting circle toward the shaft.

d) Caving method: This method is used if the deposit is a narrow, steeply-dipping one. It involves lightly blasting and loosening the ore body, then removing the ore from beneath through control chutes. Gradually the entire ore body caves down and prevents most support problems. (See Figure 5.3)

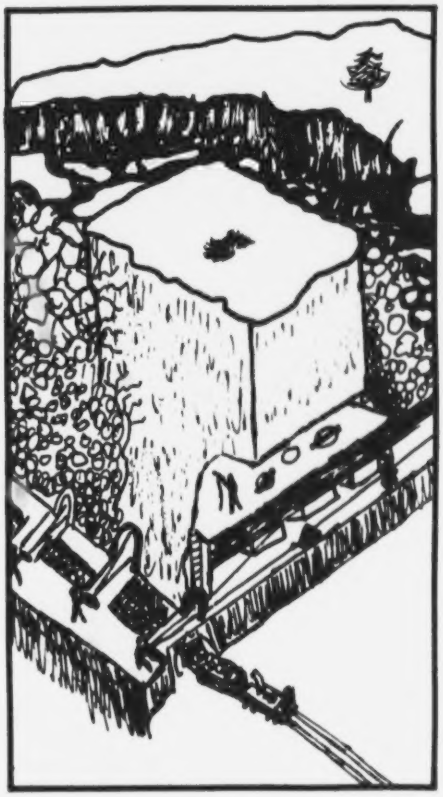


Figure 5.3. Illustrates the caving method. Notice how one block of debris has already dropped down from its original position.

3. Pumping: Oil and gas are found trapped in small openings of sandstone, limestone, and dolomite. Once geologists determine possible locations of oil deposits (faults, traps, or structural basins), a hole is drilled down to the depth of the suspected oil. If oil is present, pipes are placed in the drill hole, and pumping is begun (in some instances, enough gas or water pressure is present to force the oil to the well-head without pumping being necessary).

a) Oil and gas accumulation: Petroleum deposits may accumulate in "pools" (actually pores in sedimentary rocks). These reservoir rocks may contain oil, gas, or both, and may be accompanied by briny water from the seas. When found together, the salt water is underneath the oil, and gas is above. (See Figure 5.4) Oil and gas may sometimes be found: (1) in

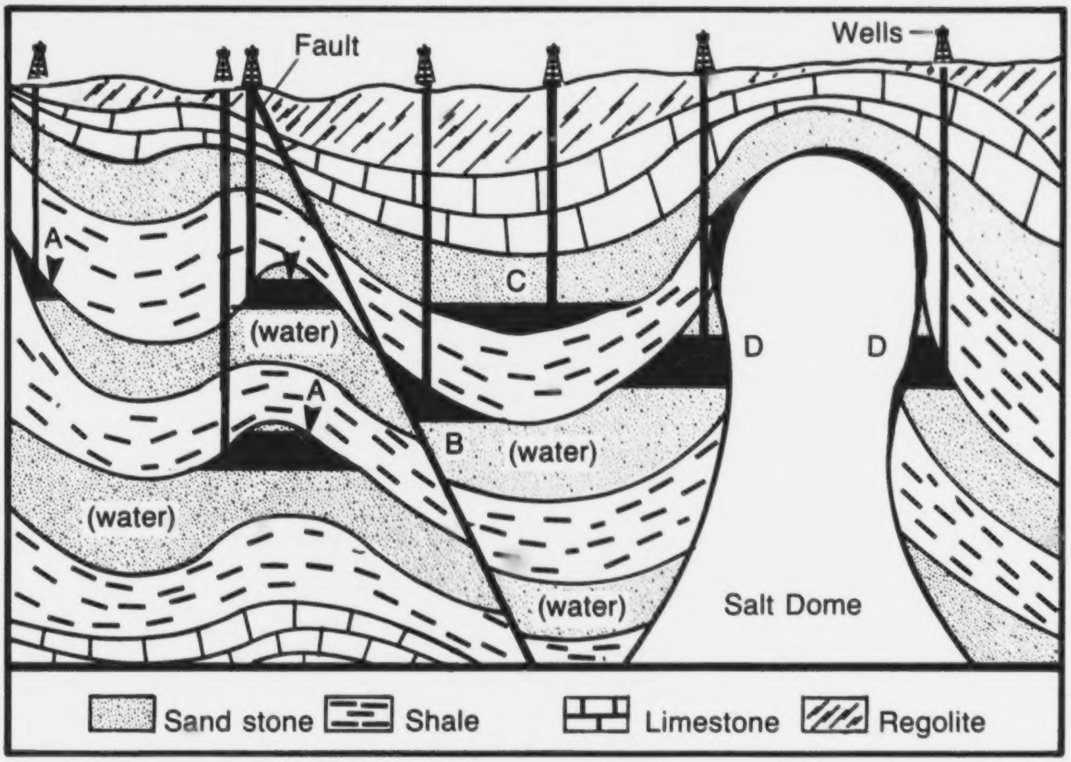


Figure 5.4. Oil and gas accumulations.

A. Stratigraphic Trap
B. Structural Trap
C. Sedimentary Basin Trap
D. Salt Dome (A type of structural trap)

structural traps (created by faulting or holding; (2) in stratigraphic traps (where porous rock grades into or is pinched off by denser rocks); (3) sedimentary basins (large depressions filled with sediments); and (4) along edges of salt domes (a type of structural trap).

b) Production techniques: Some wells are drilled into pools where the gas and water pressures are strong enough to cause a blowout (gusher). Today, in order to hold oil losses to a minimum (and to avoid pollution) a device called a blowout preventor is installed during the drilling process. Drilling is completed when the formation (rock strata) is reached that is of interest. Core samples (mud and cuttings sometimes show signs first) are tested to determine if the well is dry or a discovery (celebration!). Logging instruments are sometimes lowered in the drill hole to determine information which allows the geologist to make a judgment as to whether the well might be economically viable.

Usually, one well will not be sufficient to indicate if there is sufficient oil or gas to continue operations (unless you are a small operator and need only to cover your expenses). Capping the discovery well and drilling other "configuration" wells in an orderly pattern away from the discovery well might give the operator a better indication of the size of the strike. Exploratory wells often are plugged and abandoned until the time is right for development wells to be drilled. Can you think of reasons for waiting to bring the oil to the surface? What about the price of crude oil at the time? What about the "on-hand" supply? Who owns the bulk of the mineral rights? Are there any tax advantages?

c) Secondary recovery: When a well's production falls off, the initial solution might be to clean it out or to stimulate it through acid injection (not a trip!) or by fractioning the surrounding rock. In the primary recovery stage, gas pressure (downward) or water pressure (upward), or both, work to bring the oil to the surface. In time, these natural forces decline in strength or are wantonly dissipated by over-drilling a reservoir (witness the East Texas field: more than 31,000 wells drilled with 44 on one downtown block in Kilgore).

Pumping must now compensate for the reduction of the natural "lift" of oil to the surface. Gas and water may be injected into the strata as a replacement for the dissipated natural forces. This is known as "secondary" recovery. Even under local conditions, these conventional recovery methods (both primary and secondary) leave more than one-third of the oil locked into the formation. To recover this oil that has been left in the reservoir may be too expensive to bother. Yet, there are a number of techniques being employed. These are referred to as "tertiary", third order, enhancement techniques and include: (1) mixable recovery (CO_2 or light liquid hydrocarbons to mix with the oil); (2) chemical recovery (addition of special detergents with water), and (3) thermal recovery (injecting high pressure steam, sometimes called "fire-flooding").

For solid mineral extraction similar methods are used. In salt and sulfur mining, the Frasch process is used (see the section on *Solution and Precipitation*).

4. Surprise discoveries: On occasion, rich mineral finds are accidental. In the search for gold, prospectors in Nevada had discarded as worthless a blue rock they found. Later, the rock was identified as silver, thereby the birth of the famous Comstock lode. A similar find of silver and gold near Great Bear Lake of Canada left waste material containing black stones, identified later as pitchblend containing radium (a clock which glows in the dark has radium paint on it). Pretty stones found in streams have reportedly been turned into significant diamond finds.

IV. Milling: Mineral deposits are rarely made up entirely of the valued mineral; thus, minerals of little value usually occur with the deposit. Mineral deposits vary greatly in size and shape and require separation, or milling, before they can be used. Five to 25 tons of crude ore may be reduced to one ton of concentrated ore. This is usually done in one of four ways.

Ace
Milling
Co

A. Flotation: Finely-grained ore is stirred in water in which specific chemicals have been added. The mixture is then strongly shaken to produce a froth or foam on top. Certain minerals attach themselves to the surface of the bubbles, are floated off, and then are collected. Lead and zinc sulfides are recovered from fluorspar in this manner. (See Figure 5.5)

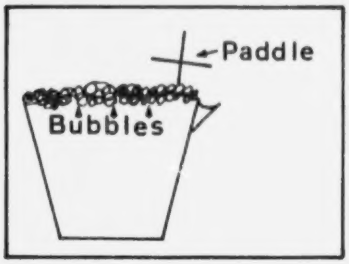


Figure 5.5. An illustration of flotation. Here the paddle skims the bubbles off the mixture into another container.

B. Gravity separation: Once again, the crude ore is finely ground, and this time it is put into a heavy liquid and stirred. The ores with a high specific gravity sink to the bottom where they can be collected. The lighter minerals remain on top. Barite is limited in this manner. (See Figure 5.6)

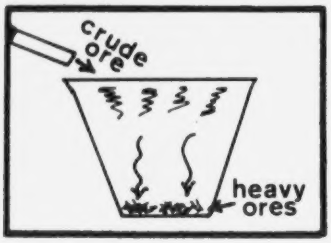


Figure 5.6. Illustrates gravity separation. Shown is the crude ore being dumped into a container. The heavy ores sink to the bottom where they wait to be collected.

C. Magnetic separation: Finely crushed crude ore is exposed to a magnet. The profitable ore is attracted to and will remain on the magnet while the waste material moves on (to the Great Gold Mine in the sky). (See Figure 5.7) It is this process that is used at the Mesabi Range in Minnesota to concentrate low-grade iron ore called taconite. Because of this recovery, the formerly worthless taconite is now a valuable resource, and it has prolonged the life of our iron deposits.

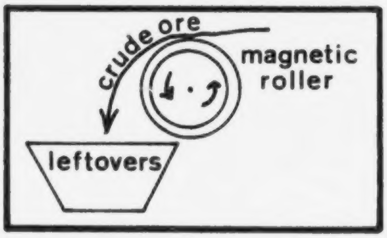


Figure 5.7. Illustrates magnetic separation. The ore that is not attracted to the magnet falls into containers and is disposed.

D. Solution and precipitation: Crushed ore is changed from a solid into a liquid state (solution) by combining it with some liquid such as cyanide or chlorine solution, acid, or water. The mineral is then separated from the solution by evaporation of the liquid (precipitation). Some early attempts at extraction of minerals from solution involved the use of wood ash to make potash. By running water slowly through wood ashes and boiling the resultant solution in open kettles, a solid white residue of potash was obtained. The potash was then used for fertilizer mixtures and plant food. A process to extract sulfur, called the *Frasch process*, uses water heated to over 140° Centigrade (300°F) and pumped underground into mineral bearing strata where it melts the sulfur. This sulfur solution is then pumped back up into drying tanks on the surface where the water is evaporated, leaving the sulfur now available for people's use. A similar process is used in mining salt.

E. Smelting and refining: Although some minerals may be extracted from air and sea water, most are found in combination with other materials in the earth. Minerals have been so important to man that the use made of the minerals actually give rise to the ages: Stone Age, Bronze Age, Iron Age, Steel Age, and Alloy Age. If rocks contain a sufficient quantity of a mineral to make it economically feasible to extract it is referred to as an ore.

1. Mineral separation: If the mineral is not found in its pure state, then it must be separated from the other rock material. In the early smelting process, charcoal (from wood) was the only carbon material used to fire the furnaces. This placed a big demand on an already dwindling supply of timber resources. Coal and coke (coal with gases and other impurities removed) became the principal fuels in the production of steel from ire ore. Oil and electricity are gaining in importance as furnace heat sources.

   If the ore is high grade (60% by volume) then it is generally sent to areas having an abundant fuel supply for smelting. Low-grade ores (copper ore is sometimes smelted with less than 2% copper) are generally smelted where they are mined. The economic aspect of location of smelting and refining will involve location of the mineral, purity of the ore, availability of fuels for smelting, transportation, and markets.

   Iron is the metal we use most today. Iron ore goes from the mine (Mesabi Range, for example) to the great smelting centers around the Great Lakes on to coal and transportation centers (Pittsburgh, for example). Now begins the initial separation from other materials in the ore through heating (coke) and the addition of a flux (a material like limestone which unites with earthy parts of the ore to form slag). This produces pig iron, a crude iron still containing impurities. Further refining is necessary to bring the pig iron to cast iron, malleable iron, and wrought iron stage.

   Most iron used today is refined into steel. Steel is produced when pig iron, scrap iron, and steel, and fuel and fluxes are again placed in the furnace. The aim of steel refining is to eliminate the impurities left after the initial smelting (into pig iron), but removal is never complete.

   Special steels are made by mixing other metals with ordinary steel. These are called alloy steels. Some changes in the characteristics of steel with one addition of other metals are: (1) hardness; (2) strength; and (3) malleability (to be shaped). Manganese, silicon, nickel, copper, vanadium, titanium, molybdenum, tungsten, and aluminum (either as elements or as ferroalloys) are a few ingredients added to steel.

   A special example of steel usage is in tin cans. Steel plates, manufactured as cans, are tinned through hot-dipping or in a electrolytic tin plate process. Other uses made of special steel include: (1) hardware and plumbing supplies; (2) hand tools for the carpenter, mechanics, and the gardener; (3) stainless steel cutlery; (4) surgical instruments; and (5) automotive parts.

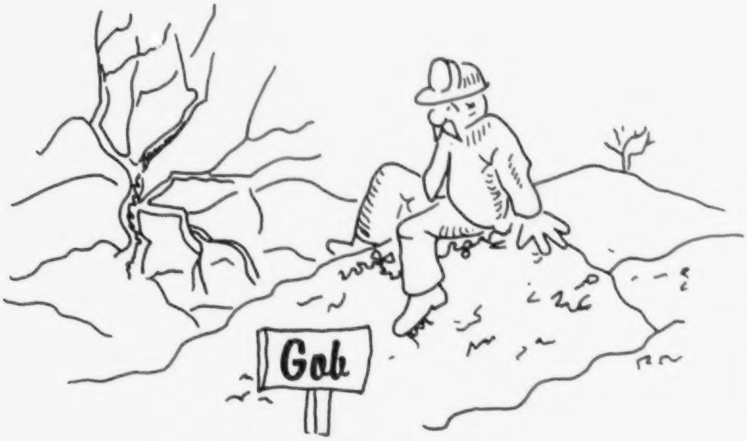
2. Beneficiation: In the beneficiation process, low-grade uneconomical ores are changed into higher-grade ores acceptable to blast furnace operators. When the higher grade ores have been depleted, processing the low-grade ores (sometimes waste mineral) by crushing, mixing it as a slurry, passing it through a skimming device (removal of lighter materials), and then passing it through a magnetic separator can be profitable. The end product of this is usually in the form of pellets. Pelletization (primarily taconite ore) has been in

progress at the Mesabi ore field for some time, and nearly as many people are involved in this as in extraction of the natural ore. A benefit derived by this (even in high-grade pelletization processing) is that it leaves much of the waste material at the extraction site, resulting in lower shipping costs and less waste disposal at the smelting plants.

3. Coal gasification and liquefaction: The process is also known as hydrogenation. In gasification, steam reacts with coal to form a high-heat-content substitute for natural gas. Compared to coal-fired electric plants, this synthetic fuel releases only one-tenth the pollution into the atmosphere. The disadvantages are the high cost, a greater loss of energy as wasted heat, and a greater release of toxic metals and organic compounds.

   In liquefaction, coal is converted to low-melting point solids, crude oil, and by-product gases by adding hydrogen and removing carbon. Sulfur and ash are removed in the process.
4. New techniques: In order to burn coal more efficiently, use less water, and reduce harmful sulfur dioxide emissions (without expensive scrubbers), new methods are being tested.
   a) Fluid-bed combination: Streams of hot air forced into the boiler suspends powdered coal and limestone (or dolomite). The limestone removes up to 95% of the sulfur. These boilers are cheaper and more efficient than conventional coal-burning boilers. The problems with the fluid-bed combustion method are the solid calcium sulfate waste and the nitrogen oxide and particulate emissions.
   b) MHD generator (magnetohydrodynamic): Crushed coal (or any fossil fuel) is treated with potassium and fired at 5000° F in this method. Chemicals released in combustion are converted to ions by the potassium. These ionized gases are forced rapidly through a magnetic field producing electricity. This method is more efficient than the fluid-bed combustion method, and it removes about the same percentage of sulfur. The particulate emission is nearly the same although the nitrogen oxide emissions are higher.

V. Environmental effects: All too often mining and milling operations do not allow plants, animals (including man), and earth materials to exist in their natural state (or any state of existence in some cases). Long before, and during, these operations by man, nature was contributing its share of environmental scars and pollution. Through the hazards of earthquakes, volcanoes, and floods and the effects of oil seeps, salt spray, and emissions of resins and gases, nature left its mark. But, left alone and in time, these scars were removed and the pollutants were cleared. But, man has added to the problem.



A. Sediment Pollution: Basic to this kind of pollution are the heaps of earth materials that are left after mining. These may be displaced overburden from strip mining, gange and tailing (nonvaluable material) from the ore, or fall-out from smelters. These detract from the visual amenities of the environment by leaving a denuded landscape consisting of holes and spoil banks. Erosion of these areas lead to pollution of our streams and ground water supplies.

B. Water pollution: Atmospheric water, soil water, ground water, and surface water may all be polluted through mining and milling operations. Gases emitted in smelting and industrial activities are cleaned from the atmosphere as "acid rain." Encroachment of salt water into fresh water supplies occurs when oil is pumped from near-ocean strata. Infiltration of polluted surface waters may contaminate ground water sources with acid wastes from mining refuse. Aquifers (water bearing strata) may be contaminated by salt water and chemicals injected into the secondary and tertiary recovery of oil. Surface waters may be polluted with sediments from mining waters, fall-out from particular materials emitted from the smelting furnaces, oil spills, or salt water from oil wells.

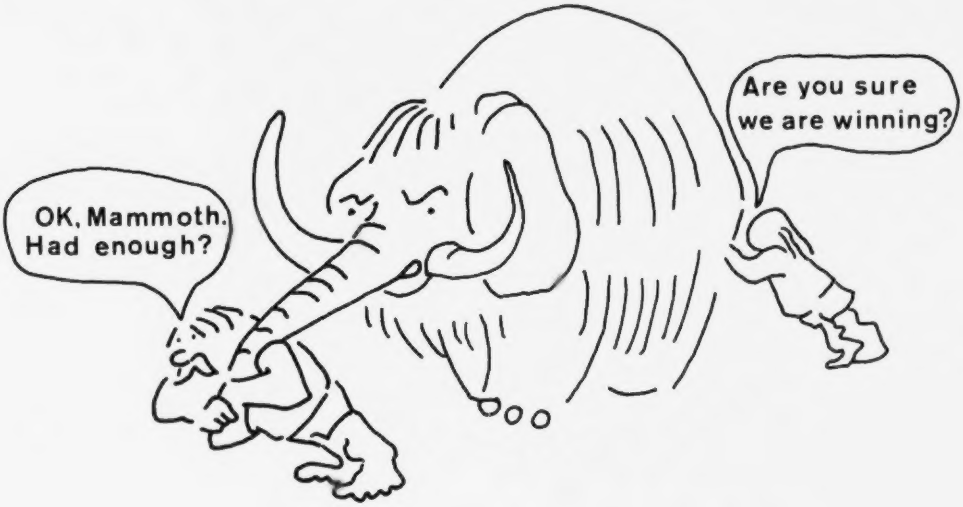
C. Air pollution: The Environmental Protection Agency is warning of a drastic change in the environment should the production of CO_2 continue at its present rate. A "greenhouse" condition could raise temperatures worldwide, causing ice (glaciers and icecaps) to melt and ocean levels to rise. The burning of fossil fuels is contributing greatly to this situation.

In mining districts, the atmosphere often reaches pollution levels harmful to plants and animals (cough-cough!). Nitrogen and oxygen are replaced by carbon dioxide, sulfur dioxide, and other trace elements. A good example of such a situation is Ducktown, Tennessee. Fumes discharged from the smelting and refining furnaces of this copper town caused widespread plant failure, and subsequent erosion created a virtual "bad lands" landscape.

D. The future: The National Environmental Policy Act (1969) requires all federal actions that could affect the environment to be preceded by an evaluation of the project and its impact on the environment (environmental impact statements, or E.I.S.). State water control boards regulate and set water quality standards. The Federal Clean Air Act (1963), the Federal Water and Pollution Control Act (1970) and the Surface Mining Control and Reclamation Act (1977), as well as state laws governing land use, sites selection, or Coastal development and management, should be a blessing to the environment.

VI. Influence of mineral resources on man's history: Mineral resources have enabled man to progress since prehistoric use was made of them.

A. Early man: The very basic quality that helped separate prehistoric man from other early primates was the ability to make and use tools. Flint, quartzite, quartz, lavas, chert, and obsidian, some of the first mineral resources to be used, provided early man with adequate materials to make axes, drills, and other implements. Man's survival margin increased with these stone tools over previously used bone and wood. With the discovery of these tools, man began to congregate, exchanging and pooling knowledge. It was discovered that through cooperation much could be contributed and learned. In addition, the sheer size of some large animals hunted for food and clothing demanded cooperation among different bands of people. For example, consider one rather unfriendly woolly mammoth. Small bands of men and their weapons would have been no match for Mr. Woolly Mammoth. However, a large group of men with weapons would have had a much greater chance of success. By congregating and cooperating, societies were also able to develop, permitting the sharing of knowledge about mineral resources and their possible value to the user.


OK, Mammoth. Had enough?
Are you sure we are winning?

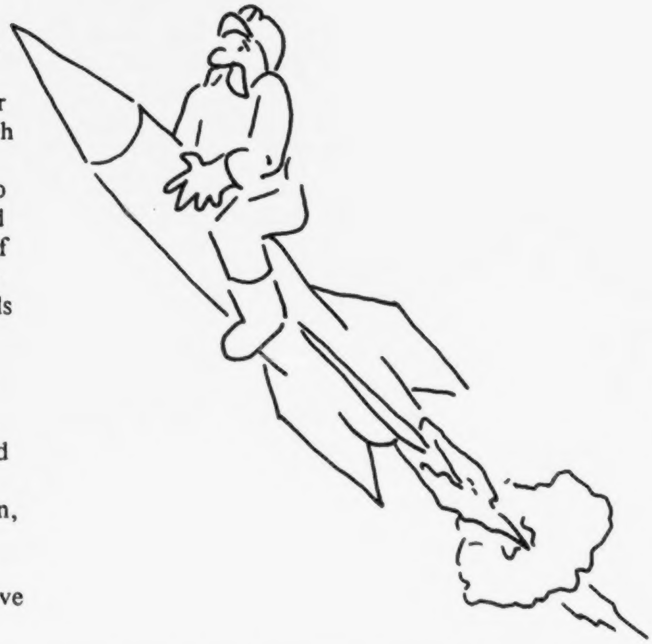
B. Stone Age: Approximately 10,000 years ago, the Stone Age began. During this time, uses of stone as tools and weapons were further developed and refined, and they became extremely effective. Knowledge about mineral resources continued to increase and with this came the ability to use softer metals such as copper and tin.

C. Copper and Bronze Age: This age began about 4,000 years ago. Copper was much softer than stone, and therefore it was much more easily molded into desired shapes. It was too soft to be used for weapons and tools. However, when it was mixed with tin, a much harder substance, bronze, was produced. Man was able to refine the tools and weapons he made as well as create new ones, more practical ones, that allowed for better efficiency. For instance, a tree could be chopped down much more quickly and easily with a sharp bronze ax than with a dull stone ax. Woodworking, now possible with bronze tools, increased the need for hardwoods which, in turn, stimulated trade. Through trade, man was able to continue sharing and expanding his knowledge of mineral resources and their uses.

D. Iron Age: Copper was too soft for most weapons. Bronze was hard, but iron was even harder which encouraged man to eventually rely upon iron. Thus began the Stone Age, about 2,500 years ago. An impressive number of tools were produced such as hinged tongs and lathes, which increased man's strength. There was a revolution in transportation, starting by simply putting an iron rim around a wheel.

MAGNIFYING GLASS
Iron rims, Bah!!
@x???
TERMITE

E. Steel Age: Late in the 1800's, a new lightweight material was discovered that was as strong or stronger than iron but was much lighter in weight--steel. Thus began an age that would lead to lightweight metals, plastics, and atomic energy. As knowledge of the mineral resources that were required to make these materials increased, so did speed and strength. Without the mineral resources needed for the new materials, nearly all of the characteristics of this age would never have developed. For example, types of transportation, starting with the first car and ending with the latest rockets headed for Mars, would not have progressed as they did.



F. Observations: In conclusion, think about each of the ages. First, note that each age became shorter than the last. Second, understand that each step in man's progress was very dependent upon the one before it. Finally, realize that we would probably be back on the level of prehistoric man if mineral resources had not been discovered and used. Even today, there are a few cultures that have remained isolated, and they have not progressed. An example of this is the Australian

Aborigines. Just the opposite, some cultures were able to bridge the ages through contact with advanced cultures. Raw materials may be present, but until these resources are developed, they are useless. To avoid using them means a lack of progress.

VII. Cycle of mineral production: There is a cycle of mineral production that a country fortunate enough to have mineral resources experiences. There are five steps in the cycle.

A. Exploration and discovery: This step is self-explanatory. Either from need or greed, a mineral is searched for and then discovered.

B. Amalgamation and consolidation: At this stage of the cycle, a company will take over the ownership of not one mine but rather several mines.

C. Industrial integration: Sophisticated products often require components that need to be produced elsewhere. Thus, industries are built to supply parts needed by other industries to create the final product.

D. Rapid depletion of cheap domestic raw materials: As industries increase in size and output, the inexpensive local raw materials are quickly depleted.

E. Decreasing domestic and foreign trade: Lack of raw materials means lack of products. As a result, there is nothing to sell either at home or abroad. The economy drops to a state of poverty.

VIII. History of mineral resources in the United States: The following is a brief, generalized overview of the United States' history of mineral resources.

A. Early history: The land now covering the area called the United States of America was new to its discoverers from Europe, but to some, it had been home for many years. The old and the new occupants used or would learn to make use of the country's vast resources.

1. Indians: Although they were considered "primitive," the Indians used many mineral resources including obsidian, flint, native copper, fluorspar, and salt.

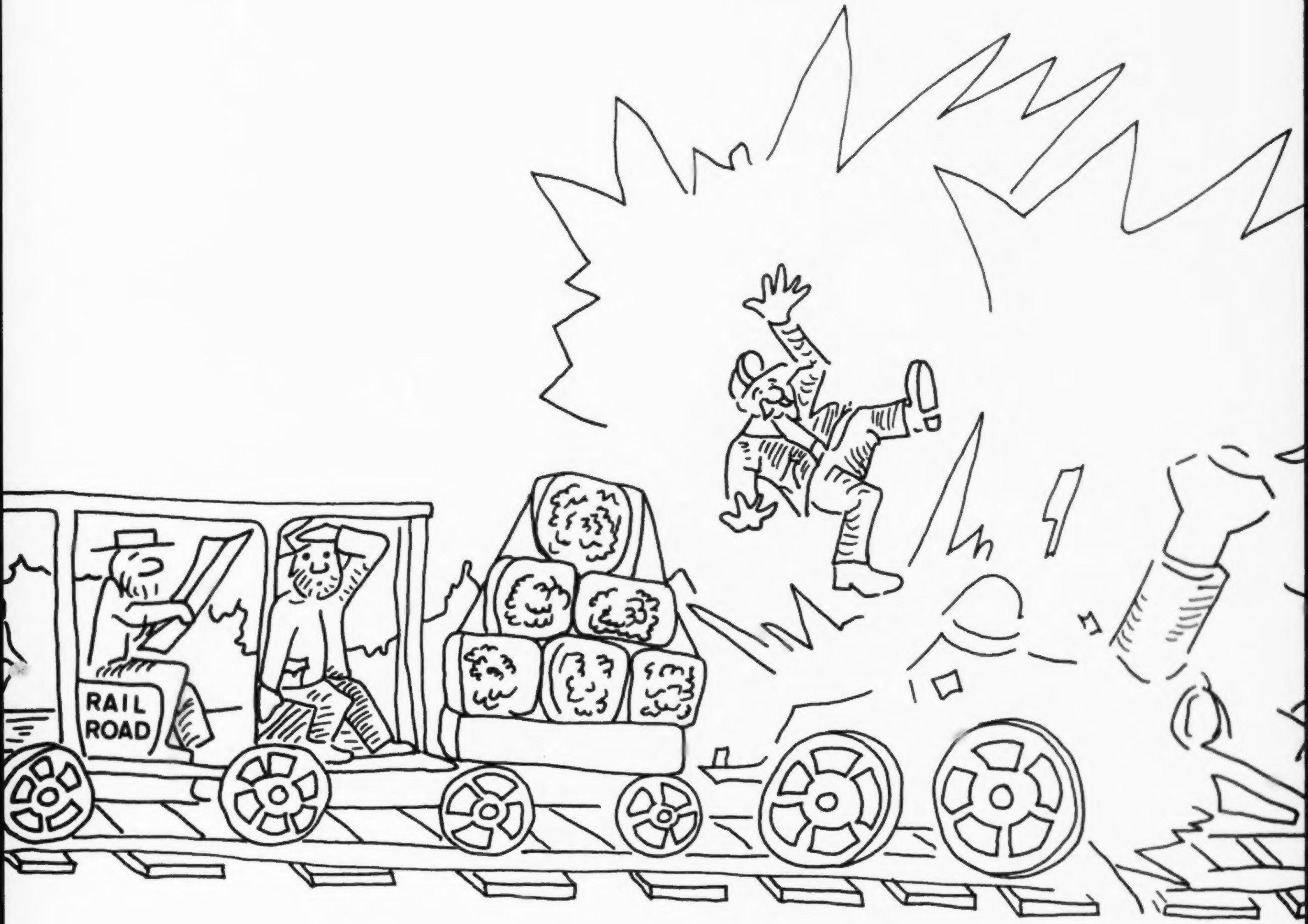
2. European explorers: They came in search of wealth--gold and silver. Although some wealth was found in the Southwest, it was not nearly as much as was expected. The explorers hoped for pure deposits. They did not want ores because they did not have the technology to separate them.

3. Colonists: Mineral exploration was limited to the necessities, such as iron. Some mineral resources were also used for bartering. When the Revolutionary War came, it caused the Colonists to become more self-sufficient because trade with England was practically destroyed. Although coal was not yet important as a home or industrial fuel, it was vital in casting iron which was needed, especially in the war; so domestic mining was strongly encouraged.

B. Expansion and mechanization: This covered a time period from 1776 through 1865.

1. Economic developments: The number of factories increased, which meant an increase in the use of mineral resources to produce goods. The United States began to change from a producer of raw materials to a manufacturing establishment providing the final product. New inventions consumed more mineral resources and at the same time encouraged more manufacturing. Such was the case with the invention of the steam engine. It required mineral resources to construct and operate it. It also opened up a new era of river travel. Transportation of products to more distant markets was now available, so factories increased their output (and their use of mineral resources) to cover a larger market. In 1865, an important event in American mineral history occurred--the beginning development of the iron ore deposits of the Lake Superior region. The United States then had a large supply of iron ore with which to make steel. This also created a demand for coal that was needed to make steel.

2. Opening the West: Westward expansion began with farmers and settlers wanting "elbow room." They were followed by miners searching for gold and silver, two mineral resources upon which the United States' monetary system is based. A few railroads began to crawl west to accommodate expansion. To build the railroads required mineral resources such as steel; however, train fuel remained to be wood, at this point. (The early steam locomotives were somewhat comical in sight with their car of cotton bales between the engine and the passengers to protect the passengers from possible explosion.)



3. Civil War: Based on mineral wealth alone, it was inevitable that the North would win the Civil War. By the 1860's, northern industry was large, consuming iron, coal, and other minerals in massive amounts. This enabled the North to produce munitions and other war supplies. Even southern Illinois had its glory by building ironclads (a warship covered with thick iron plates) from bog iron, coke, and limestone located near Mount City. The North had another advantage over the South because they could import mineral resources from Europe through northern shipping. The South was at a disadvantage because they

had few mineral resources, and they could not obtain additional supplies because their harbors were blocked by the Union Navy.

C. Industrial period: Manpower shortages during the Civil War led to the emphasis on labor-saving machinery (automation). To accomplish this required more mineral resources to make and run machinery and to produce final products. The Industrial Revolution was promoted.

  1. Post Civil War: Since the North was rarely invaded during the war, its industries were free from the destruction of battle. Consequently, northern industries flourished with no pause for cleanup after the war. Railroads also increased, and all of these developments added to the need for mineral resources. More mineral resources were discovered as were uses for them, such as petroleum-based pharmaceuticals, machine lubricants, and stoves that cooked with gas. The United States was becoming an industrial giant with gigantic needs, especially for steel, other metals, and coal.
  2. Westward rush: There was an increase in mining, especially lead and silver. This fell into a pattern of someone making a discovery and others following to mine the resource. Railroads were built to accommodate the mines, and in so doing, they consumed more mineral resources (now including coal instead of wood for fuel).
  3. Conservation: The United States began using vast amounts of resources; the more used, the more needed. During this time, coal beds in the Appalachians were opened up. Iron ore continued to be unearthed. Petroleum was discovered. During the 1860's and 1870's, some people were beginning to have a strong opinion in favor of protecting or making wise use of the nation's mineral resources. The 1872 Mining Law established the rules for the use of public land resources. In 1879, the United States Geological Survey (USGS) was formed for the purpose of scientifically studying our mineral resources.

D. Twentieth century: In 1900, Europe was still the leader in the Industrial Revolution, but it was reaching the point where it was necessary to import mineral resources to maintain its present rate of production. At the same time, the United States was self-sufficient in the mineral industries. The Industrial Revolution was in full swing.

  1. World War I: In 1916, England began to buy vast amounts of mineral resources from the United States. In 1917, we, with our vast resources, entered the war. As an indication of the importance of mineral resources, the President was given the power by Congress to control our mineral resources in the interest of winning the war. Manufacturing boomed. Technology increased the use of mineral resources. For example, planes were built; they required mineral resources for their construction, maintenance, and operation. Because we enlarged our productive capacity for the war effort, by 1918, we were the world's richest, strongest, most highly industrialized nation, thanks to our mineral wealth and self-sufficiency.
  2. Post World War I: With the help of advanced machinery, new industries flourished during the 1920's. New automobiles were the rage, and they consumed large amounts of gasoline. America's rich mineral resources were consumed in enormous amounts; the more we used, the more we needed. Briefly, during the Depression in the 1930's, there was a decrease in mineral resource usage because manufacturing declined.
  3. World War II: Once again, we assumed the task of furnishing war supplies. Manufacturing plants expanded as did the need for mineral resource and to a greater degree than man had ever known. Technological advances associated with the war included radar, atomic weapons, and atomic power. These required newly discovered mineral resources in addition to presently used ones. Products in the form of antisubmarine devices, aircraft carriers and landing craft, tanks, war and merchant vessels, munitions, and other war material greedily gobbled more and more mineral resources.

4. Post World War II: There was a demand for industrial output nationally and internationally; thus, the demand for mineral resources continued to increase. United States' mineral resources experienced a heavy drain, and it became necessary to use lower-grade ores and to increase imports from other countries in keeping up with the demand. Even with our vast resources, the country's self-sufficiency was seriously reduced.
5. Energy crisis: The mineral crisis really started before the "Energy Crisis of 1973." A problem occurred which caused Americans to pause and consider our lifestyle in relation to mineral resources. A political situation evolved in which the Arabs withheld oil from the United States. This resulted in gasoline prices nearly doubling, inadequate supplies of gasoline, and the realization of the large number of products made from oil. Americans could not function as smoothly in their present lifestyle and realized there was a genuine crisis. As Americans looked at the other resources, Americans learned there were also problems with resources other than oil.
6. Present: We are now attempting to solve our problems, although the future is not optimistic. Conservationists are encouraging wise usage of mineral resources while pointing out needless waste. Scientists are searching for different forms of energy. Recycling is encouraged as often as possible. New technology is forging ahead to aid where possible.

SEE ACTIVITY 5.2

Feast or famine—it is your choice!

IX. Earth's energy sources: The demand for energy resources is steadily increasing as population continues to grow and standards of living try to keep pace. With greater emphasis now being placed upon the quality of the environment, changes in the energy use patterns may be soon at hand.

A. Coal: Because of a limited reserve of oil and gas, coal is becoming necessary increasingly important as the energy provider in thermoelectric power generation and industrial usage. As it is also used in the production of gas and oil through gasification and liquefaction, more and more pressure will be placed on coal producers and, consequently, upon the environment. Increased production means more land taken out of agricultural usage, degradation of landscape, and adverse environmental effects on soil, water, and air.

Countries with large reserves of coal are: U.S.S.R., U.S., China, and Canada.

B. Oil and gas: Based upon estimates of proven reserves in the United States in 1975, we should now be out of gas and have about 2 years of oil left. If we use estimates of inferred and undiscovered resources, we can envision the supply lasting past year 2000, at the current rate of usage. It is extremely difficult to predict the end to this petroleum-based era, but without new accumulations (like Prudhoe Bay), we, in the U.S., are destined to be dependent upon foreign oil producers, or we must develop alternate energy sources.

Proven reserves of oil and gas are found: (1) in the Middle East (Saudi Arabia, Kuwait, Iran, and Iraq); (2) in lands surrounding the Gulf of Mexico and the Caribbean Sea; and (3) in the U.S.S.R. (estimates are that the U.S.S.R. may have twice the reserves of gas as does the U.S.).

C. Oil shale: Petroleum (of sorts) is found in pore spaces of sedimentary rock in forms of tar (Le Brea Tar Pits), bitumen (Athabasca sands of Alberta, Canada), asphalt, and pitch. But, as a proved reserve, oil shale is a possible solution to the oil crunch. But it is still too expensive to produce oil from oil shale. It takes approximately one and one-half tons of oil shale (actually bitumen in marlstone) to produce one barrel of oil. Processing this rock will require much energy (heat), will release large quantities of noxious gases and pollutants, will require lots of water (in an arid region), and will create much waste material. So, the Green River Formation in Colorado, Utah, and Wyoming must wait until the oil in basins and traps has been recovered.

D. Nuclear energy: Since the splitting of the atom in the early 1940's, developing technology led the world into the nuclear age. Heat from the fission reaction (uranium) is used to produce steam to drive electric generators. One can compare the nuclear reactors (furnace) to the boiler (fired with fossil fuel).

In the entire cycle using this energy source, from mining to processing the ore to final disposal of waste, some radiation enters and affects the environment. It is this that is foremost in the minds of people--what about the hazards of nuclear energy? What can we do with the radioactive waste? What are the chances of a reactor leak? Can we prevent a "run-away" nuclear reactor accident? Is it worth all the worry? But, it may someday provide an unlimited cheap energy source for the world.

Instead of fission, what are the prospects for fusion energy. The sun fuses hydrogen as an energy source--can we? If we could produce temperatures high enough, and could avoid an explosion, maybe!

E. Solar energy: Earth intercepts about 1/2,000,000,000*th* of the total solar radiation. Yet, this is enough to make earth warm enough for habitation. But, can we collect solar radiation, store the energy, transform it into electrical power, and transport it to the consumer at a reasonable cost? Not yet! Do you remember concentrating rays of the sun with a lens on a piece of paper to start a fire? You were using solar energy then. Today, heating and cooling of homes is a reality. Large-scale solar energy development may be a far piece down the road.

F. Water power: Energy produced by running water is expected to increase, but at a decreasing rate. The best sites for dams have been utilized, and many laws have been enacted which protect rivers from development.

Water power supplies about 4% of the total energy produced in the United States and is developed to only about one-quarter of its maximum.

F. Geothermal energy: In the conversion of natural heat from the interior of the earth to generate electricity and for heating of buildings, there appears to be less extensive adverse environmental impact than from the use of federal fuels. It does not produce particulate pollution or radioactive waste. It does create a problem of hot waste water, highly saline and corrosive. Withdrawing the water causes surface subsidence, and if waste-water is re-injected into the reservoir, earthquakes may be caused.

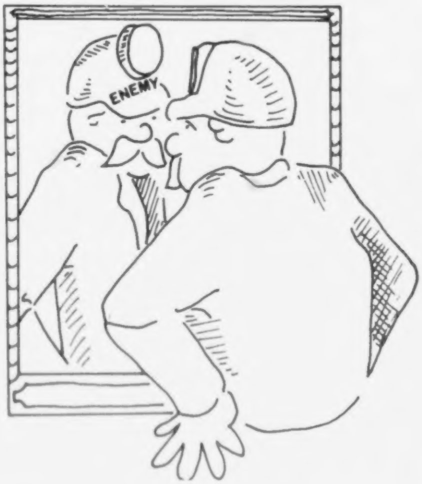
There are 2 natural sources of geothermal energy (in the form of hot water and steam) to run turbines in the production of electricity. One is provided in hot springs and geysers. The other is the deeper zone of hot ground water which can be tapped by drilling.

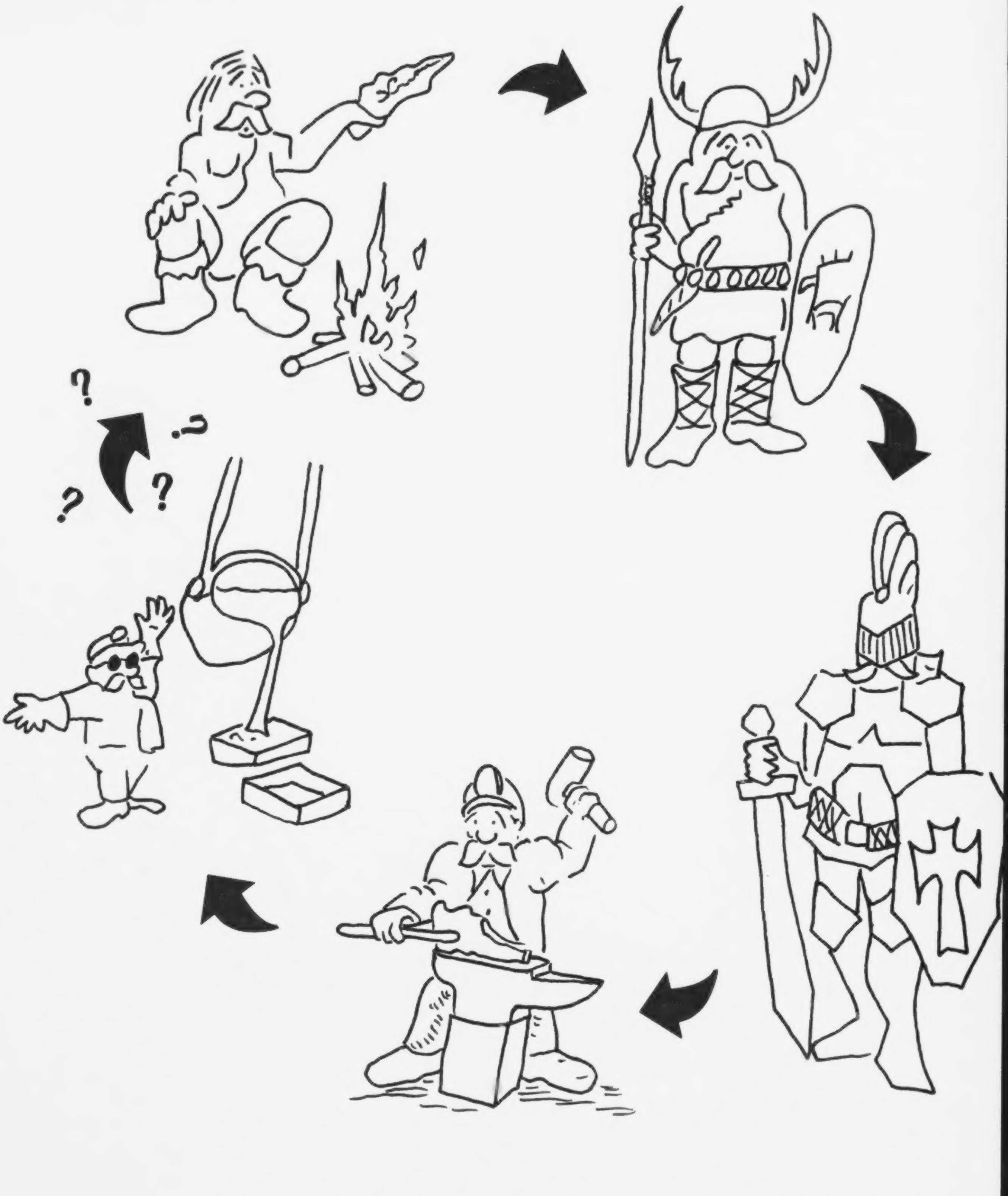
New Zealand, Mexico, Italy, Japan, Iceland, U.S.S.R., and the United States have existing geothermal facilities. The estimates of reserves of geothermal energy in the Imperial Valley alone would provide enough electricity for southern California if full production could be realized.

H. Wind power: Although it is interesting to read about Don Quixote jousting with windmills, the fact remains that wind is not a reliable source of energy. Wind is dependent upon solar energy for its being, and it is difficult to store. Historically, it was important in the development of power in the low countries of Europe and in the early settlement of the Great Plains.

I. Tide power: Tidal-electric power plants are in operation today. In areas of the world where the rise and fall between high and low tides (tidal range) is considerable, tidal energy may prove economical. Because it interferes with shipping and fishing, this energy source may not be developed to any great degree soon. Experiments are also being conducted in oceans to determine if the density and thermal gradients present could be used to run turbines. In the twenty-first century, after the fossil fuels have been depleted, and the carbon dioxide in the atmosphere has created a greenhouse condition on earth, who knows which energy source (or sources) will be in greatest demand.

X. Summary: Mineral resources are one of the main reasons of the comfort in our lives. Mineral resource-forming environments are not bound by national boundaries; thus there are "have" and "have-not" nations. A look at formative environments such as the hot molten rock below the earth's surface or the rolling waves of an ocean would not make them seem relevant to the car we are driving or the T.V. set we are watching. Only through a series of steps from the discovery of the mineral resource, through its mining process, and ending with the manufacturing of the final product does one see a relationship. The development of mineral resources has been a gradual process occurring over thousands of years, and it is still continuing. Our present status could conceivably be just one more step in the progression of developments. As mineral resources continue to be developed, so will their influence on our personal lives, our state government, our national government, and our entire world. "Mirror, mirror, on the wall..."





Chapter 5: Problems and Questions

1. Explain how the use of the term "mineral" varies in this mineral resources chapter from the mineral chapter.
2. Compare and contrast mineral resources, mineral reserves, and mineral deposits.
3. Why are mineral resources considered finite?
4. What determines whether a mineral deposit is worth mining?
5. In the United States, we have 6 percent of the world's population, yet we consume 35 percent of the world's energy. What problems might result from this?
6. Briefly describe how mineral resources influenced man's history.
7. How can knowledge of how a mineral is formed aid in possibly locating that mineral?
8. Explain three (3) mining methods. Give the circumstances when each is used.
9. Explain three (3) of the different milling methods used to extract minerals from ore, and name a mineral resource that is milled by each process.
10. Name three (3) environmental problems that may result from mining, milling, or using mineral resources.
11. Describe the complete cycle of mineral production.
12. In a word or two or three million, describe the United States' present mineral resource status.
13. As mineral resources are used at an increasing rate due to increased demand and population, what political and economic problems might result? Name three (3).

UNIT CONTENTS

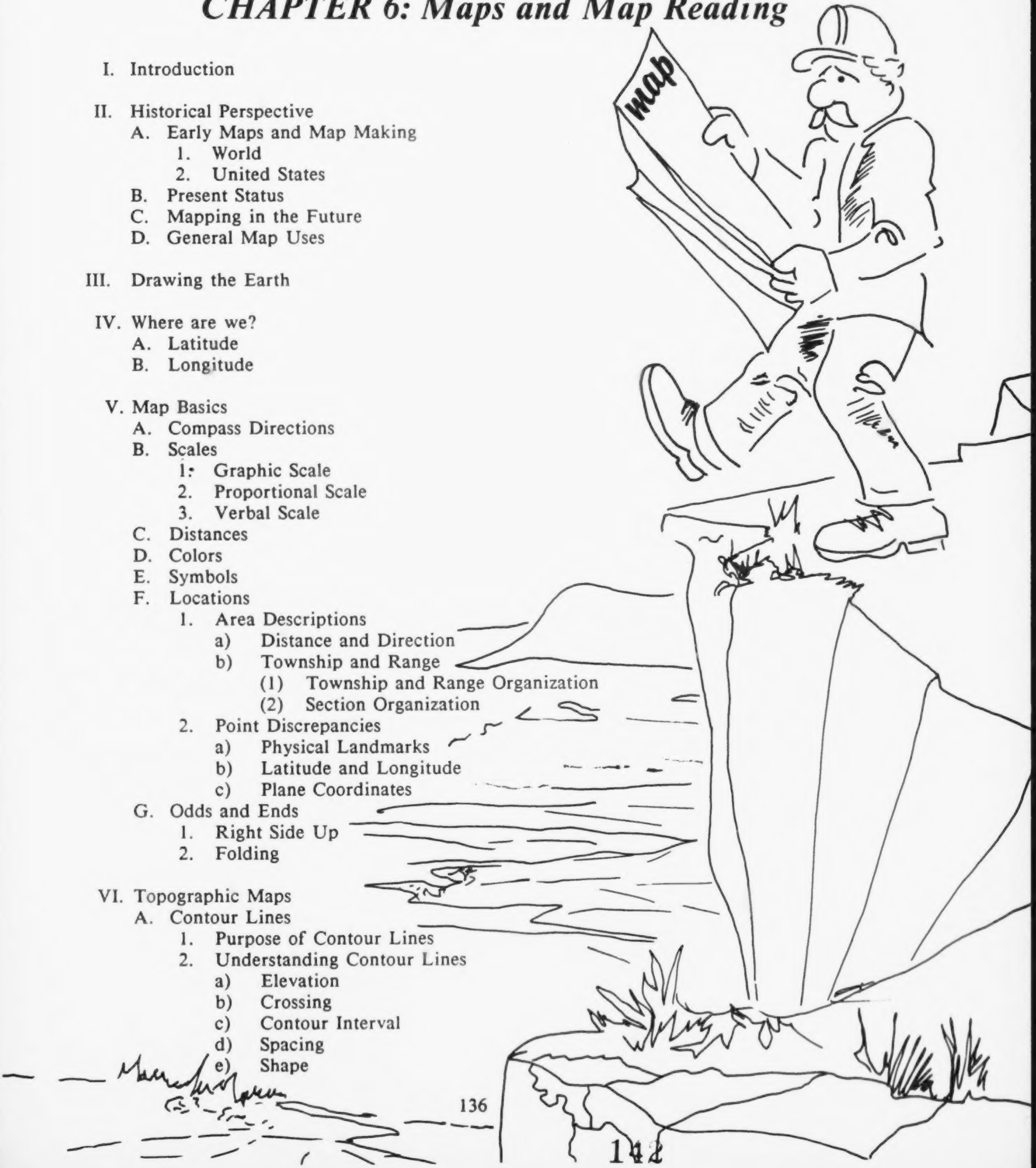
UNIT III

Observing the Earth

Chapter 6 Maps and Map Reading
Chapter 7 Aerial Photographs

Unit III: Observing the Earth

CHAPTER 6: Maps and Map Reading



I. Introduction

II. Historical Perspective
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    2. United States
  B. Present Status
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  D. General Map Uses

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    - 2. Map Orientation
    - 3. Map Margins
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        - b) Latitude and Longitude
        - c) Grid Systems
            - (1) Latitude and Longitude Grid
            - (2) Letter and Number Grid
    - 5. Scales and Distances
        - a) Proportional Scale
        - b) Graphic Scale
    - 6. Symbols and Colors
        - a) Blue
        - b) Black
        - c) Red Tint
        - d) Red
        - e) Green
        - f) Purple
        - g) Brown
    - 7. Contour Lines
    - 8. Map Profiles or Cross-sections
- D. Uses for Topographic Maps

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- A. Making a Geologic Map
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    - 3. Drawing Rock Boundaries
- B. Identifying Rock Structures
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VIII. Summary

Related Activities

Vocabulary

Determine different map features and uses.

Determine compass directions from a given amount of information.

Relate the different scales to each other and to distances on the ground.

Measure distance on a map.

Demonstrate problems in creating map projections of the earth's surface.

Identify latitude and longitude and locate specific points on earth using latitude and longitude.

Describe an area using distance and direction or metes and bounds.

Locate designated areas using township and range method.

Locate designated areas within a section.

Do a point description of a physical landmark.

Make point descriptions using latitude and longitude.

Use the skills of map basics in reading an Illinois highway map.

Interpret information from contour lines on a map.

Draw a profile of a contour map.

Calculate the gradient of various points in given situations.

Locate specific points using township and range method.

Use the latitude and longitude grid method (rectangular system) to locate specific points on topographic maps.

Use the letter and number grid method to locate specific points.

Identify map symbols on a topographic map.

Interpret contour lines on USGS topographic maps as to landform shapes, relief, and elevation.

Draw freehand profiles of topographic maps.

Review all of the topographic map basics.

Identify information provided by a geologic map.

Problems and questions

Mapping Geo Facts

Some of the early surveying methods were humorous. In the West, cowboys made use of their cigarettes they rolled with Bull Durham tobacco. Occasionally, they measured the boundaries of ranches and rangelands by their homemade smokes: "Thirty Bull Durhams north, fifteen east."

Some humorous names can be found on maps: Chucklehead Diggings and Mugfuzzle Flat, California; Sleepy Eye and Embarrass, Minnesota; Bumble Bee, Arizona; Cuckoo, Virginia; Eek and Purgatory, Alaska; Loco and Okay, Oklahoma; No Bob, Kentucky; Goose Egg, Wyoming; No Man's Land, Massachusetts.

Chapter 6: Word List

Topo Talk Terms

Area description
Base line
Base map
Bench mark
Cartography
Contour interval
Contour line
Depression
Dip
Distance and direction (area description)
Equator
Exaggerated vertical scale
Geographic grid
Geographic north
Geologic map
Gradient
Graphic (bar) scale
Grid
Hachure line
High relief
Horizontal scale
Index contour
Large scale
Latitude
Legend
Letter and number grid
Longitude
Low relief
Magnetic declination
Magnetic north
Map
Map Projection
Meridian
Mosquito distribution map
Natural scale
Parallel
Plane coordinate
Point description
Physical landmark
Prime Meridian
Profile
Proportional scale
Quadrangle
Range line
Relief
Scale
Sea level
Section
Slope
Small scale
Spot elevation
Strike
Topographic map
Topography
Township and range
Township line
Verbal scale
Vertical rock column
Vertical scale

Straight Terms

Coincide
Denote
Depict
Designate
Exaggerate
Hemisphere
Profile
Traverse

UNIT III: OBSERVING THE EARTH

Chapter 6: Maps and Map Reading

I. Introduction: This chapter involves the development and understanding of maps and map features. Upon the completion of the chapter, you should be able to interpret and analyze surface and subsurface features that result from geologic activities. Remember, a map is quite simply a drawn representation on a flat surface of a part of the earth's surface. Cartography is the science and art of map construction.

II. Historical perspective: Maps have been in existence nearly as long as man has. And, as man has evolved to become more sophisticated, so too have maps. Recall, though, that we have both had humble beginnings before reaching our present-day status.

A. Early maps and map making: One of the oldest forms of communicating knowledge was through the use of maps. Mapping has had a long, interesting history. Maps have been used by man since recorded history began; in fact, map-like drawings existed in prehistoric cave dwellings.

1. World: The best known of all early map makers were the Marshall Islanders who made charts of their islands and wave fronts by attaching snails to palm-leaf ribs. the Egyptians measured, then mapped the land for taxation purposes. During the Middle Ages, a more advanced map, a portolano, was developed by seamen. It outlined seacoasts; the first to be done was of Mediterranean. As man explored new continents, the portolano was expanded (See Figure 6.1)

2. United States: The first map to be entirely produced in America was a woodcut of New England. In colonial America, the most important mapping was dependent upon military interests. As Colonists moved westward, settlers, trappers, miners, and railroaders provided additional maps. As states formed, most state legislatures financed the publication of "official" state maps.

B. Present status: Today, most of the world has been mapped. The earlier maps had to be made by surveys in the field, and they took many years to complete. Now, with the assistance of space satellites taking photographs of the earth, new and updated maps are easy to obtain.

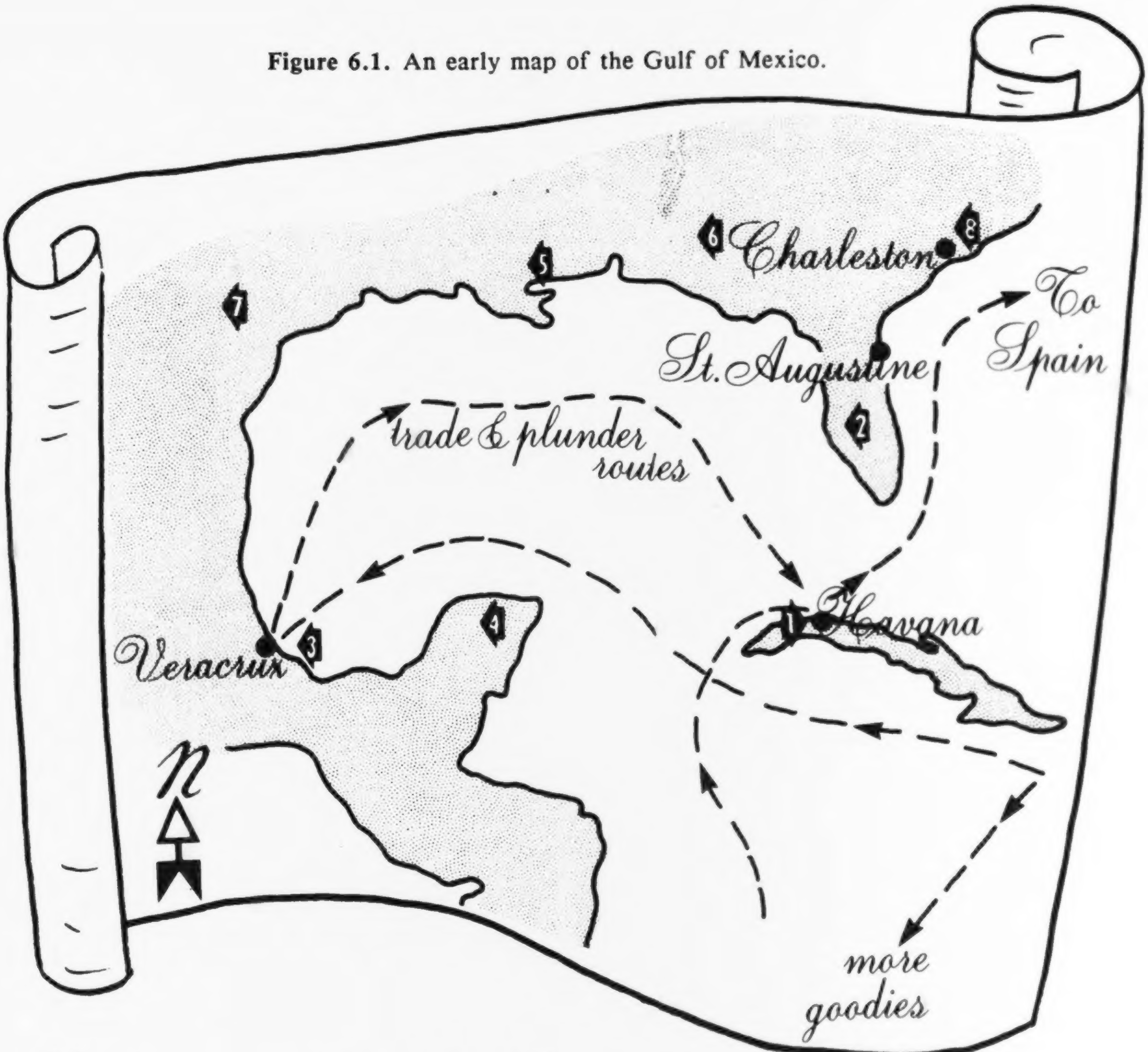
C. Mapping in the future: With the use of newer, more sophisticated satellite equipment, maps will be produced with additional details and accuracy. These maps will pinpoint such features as mineral deposits, geologic hazards, and pollution sources, as well as give us better maps for general purposes.

SEE ACTIVITY 6.1

D. General map uses: Maps are used in many ways. Already this school year, maps have had an important function in your lives. They have guided you to the correct classrooms at the beginning of the school year. If you had a fall field trip, they directed you to all of the steps. Through their use, you safely returned to the school (YEA!) instead of ending up marooned in an unplanned location, such as sunny Florida (BOO!). People use maps to show data about the earth's surface. Political maps show national and local boundaries and indicate relative sizes of towns. Navigation charts provide navigators with routes and distances. Hydrographic maps are useful for showing depth of water and shape of the sea floor. Topographic maps show the shape and elevation of the land. Geologic maps show the arrangement of rock formations. Mosquito distribution maps are of utmost importance to hungry mosquito eaters. Think of some additional uses for maps.

III. Drawing the earth: To deal with surface features of the earth, it is necessary to locate them accurately and to record important details. Because a world globe has about the same shape as the earth, it is the most accurate representation of the earth available. A serious problem of distortion occurs when the features on the curved, nearly round surface of the earth are transferred onto a flat map. The techniques by which these features are transferred are called map projections. To understand what occurs during a map projection, imagine a

Figure 6.1. An early map of the Gulf of Mexico.


6
Charleston
8
5
7
To Spain
St. Augustine
2
trade & plunder routes
Havana
1
4
Veracruz
3
N
more goodies

1. Get cigars; watch out for Russian missiles
2. See Disney World (under construction, completed in 250 years)
3. Good tacos; buy some Rolaids
4. Plunder gold and silver; leave some plague
5. Visit Mardi Gras (do not go in June)
6. Get some peanuts and Billy Beer
7. Visit Willie Nelson's house
8. Tobacco center of the New World (free lung cancer)

transparent globe lighted from inside. Surface markings, such as lines, cast shadows on a piece of paper held against the lighted globe. Differences in the manner in which the flat paper is held against the globe produce a variety of patterns in the shadows cast. The paper may be held flat, wrapped like a cylinder, or shaped into cones. (See Figures 6.2, 6.3, and 6.4)

SEE ACTIVITY 6.2

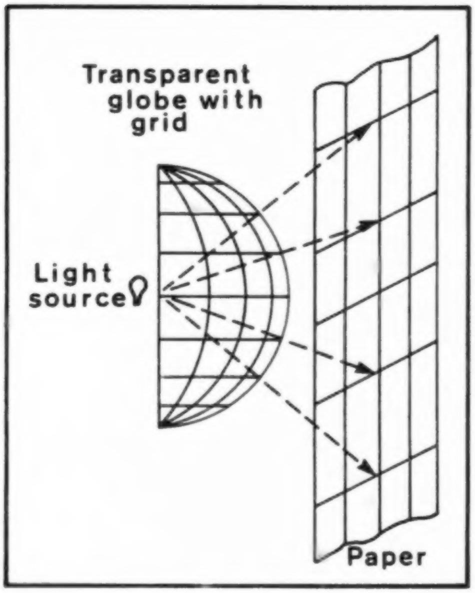

Transparent globe with grid
Light source
Paper

Figure 6.2. Illustrates the general setup for a map projection. The light rays reflect lines onto a flat sheet of paper.

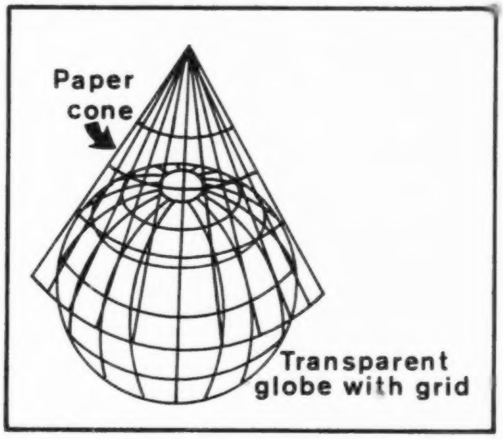

Paper cone
Transparent globe with grid

Figure 6.4. Illustrates the setup for a simple conic projection. The light rays reflect lines on paper wrapped in the shape of a cone.

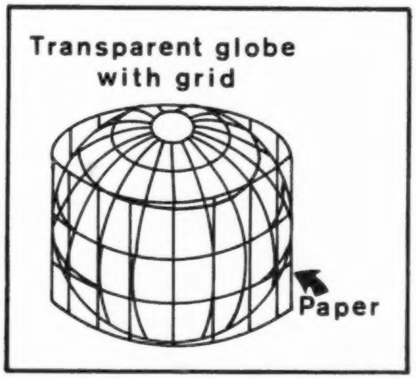

Transparent globe with grid
Paper

Figure 6.3. Illustrates the setup for a simple cylindrical projection. The light rays reflect lines on paper wrapped in the shape of a cylinder.

IV. Where are we? In describing locations on the earth's surface, imaginary lines such as those seen in Figures 6.2, 6.3, and 6.4 are used to divide the earth into sections. This network of lines is called a geographic grid. Because circles are measured in degrees, the grid lines are measured in degrees. To provide greater accuracy in measuring distances, each degree (^{O}) is divided into 60 minutes ('), and each minute is divided into 60 seconds (").

A. Latitude: The earth's equator is the reference line for measuring distances north and south. The equator is an imaginary line halfway between the poles. It divides the earth into two equal half spheres. North and south distance from the equator is called latitude and is marked by the imaginary lines called parallels. These lines are parallel to the equator and to each other. Every point on the same parallel is an equal distance from the equator. The equator is 0^{O} latitude, and the North and South Poles are both 90^{O} latitude. For further understanding, consider that the latitude of any point is the degree of the angle measured from the equator to the center of the earth and back to a given point. (See Figure 6.5) Any location north of the equator is measured in degrees of latitude north. Any location south of the equator is measured in degrees of latitude south. A point halfway between the equator and the North Pole would be what latitude?

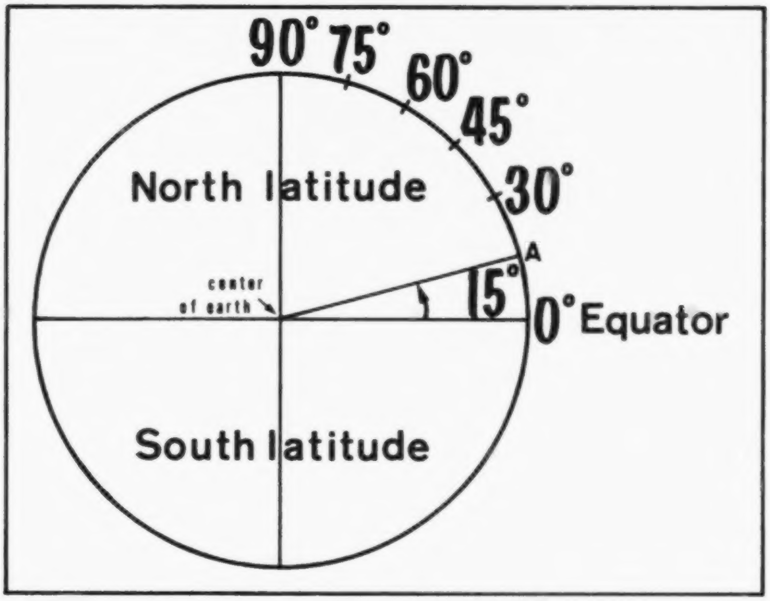


Figure 6.5. Illustrates degrees of latitude. The 15^{O} indicates the angle between the equator, the center of the earth, and point A.

B. Longitude: The other set of lines of the grid system go from the North Pole to the South Pole and measure east and west direction. These imaginary north-south lines are called meridians. The meridian which passes through Greenwich, England, was arbitrarily selected as 0^{O} longitude and is called the Prime Meridian. All meridians west of the Prime Meridian to the 180^{O} meridian mark the degrees of west longitude. The longitude of any point is the degree of the angle measured from the Prime Meridian to the center of the earth and out to a given point. All meridians meet at the North and South Poles. (See Figure 6.6)

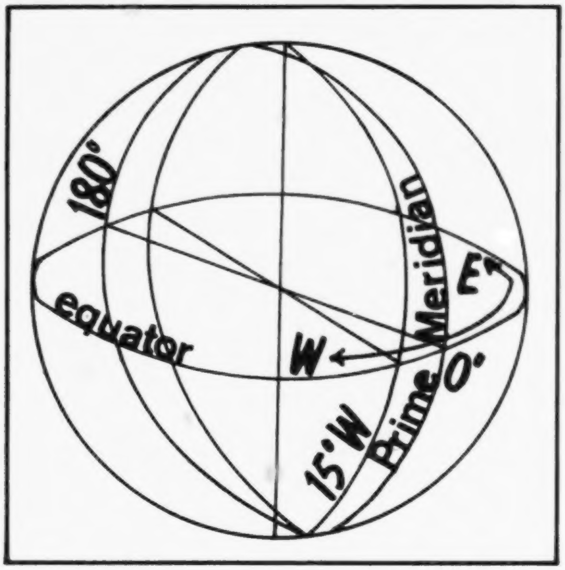

180°
equator
W
E
Prime Meridian
0°
15°W

Figure 6.6. The meridian of longitude shown here is 60° west of the 0° or Prime Meridian.

The location of any place on earth can be precisely given by latitude and longitude. For example, Washington, D.C., lies at latitude 38°53'N (north) and at longitude 77°01'W (west). (See Figure 6.7)

SEE ACTIVITY 6.3

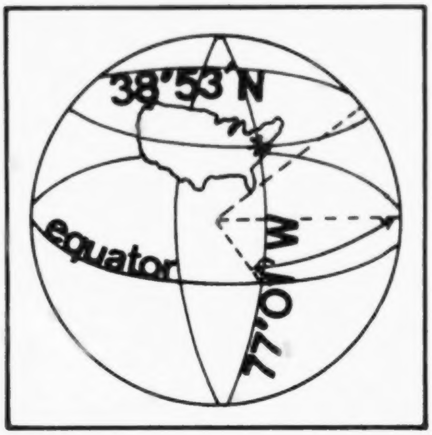
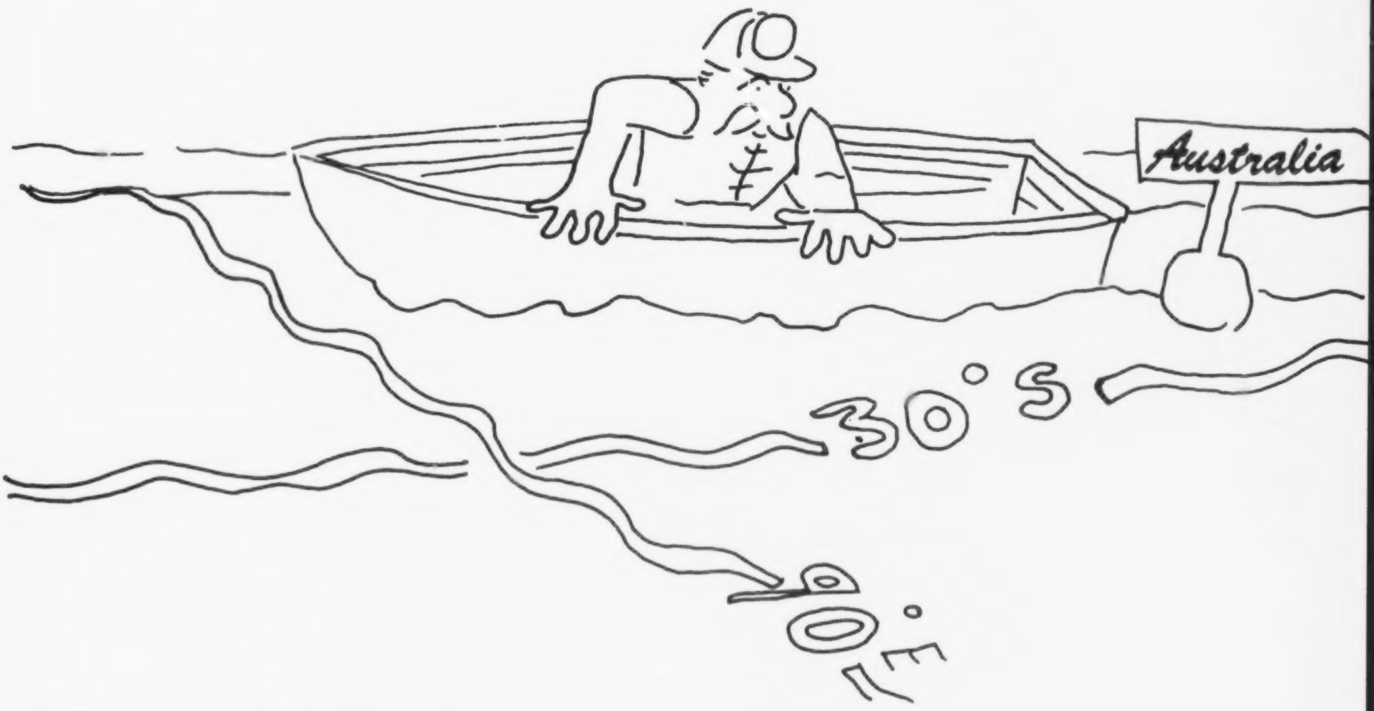

38°53'N
equator
77°01'W

Figure 6.7. To locate Washington, D.C., it is necessary to measure 38°53' north of the equator and 77°01' west of the Prime Meridian.



V. Map basics: There are several standard features found on nearly every map. It is agreed by most authorities that every formal map must have these five basics: title, scale, legend, basic grid, and compass directions. In Units I and II of this text, the Metric System of measurement was used. However, in this Chapter and in Chapter 7, the United States System will be used, because USGS topographic maps are based upon this system.

A. Compass directions: On every map, compass directions must be known if the map is to be of any use. The most common method of showing compass directions is to designate the top of the map as north, the right as east, the bottom as south, and the left as west. However, probably the first rule of all map makers (and that includes you, friends) is to put a directional arrow on EVERY map, pointing to the north. Always check to make sure you know which edge of the map is north. It is unwise to assume north is at the top of the map. More specific directions can be made by dividing the 360 degrees of compass direction into 16 equal parts. In so doing, the divisions between each of the four directions allow three additional, more specific directions. The 45 degree division between each of the four main directions is designated in name by using the two directions between which it is located. (North or south are always said first.) Thus, we have northeast, southeast, southwest, and northwest. Eight more divisions are used, dividing each of the 45 degree divisions in half. These are designated first by the main direction they are closer to followed by the 45 degree direction name. Hence, there are north-northeast (NNE), east-northeast (ENE), east-southeast (ESE), and south-southeast (SSE), for example.

SEE ACTIVITY 6.4

B. Scales: All maps must have some basis for comparison between actual distance on the earth's surface and the same distance represented on a map. This is called the scale of a map. Large scales show smaller areas and give more detail, while small scales show larger areas and give fewer details. (See Figure 6.8)

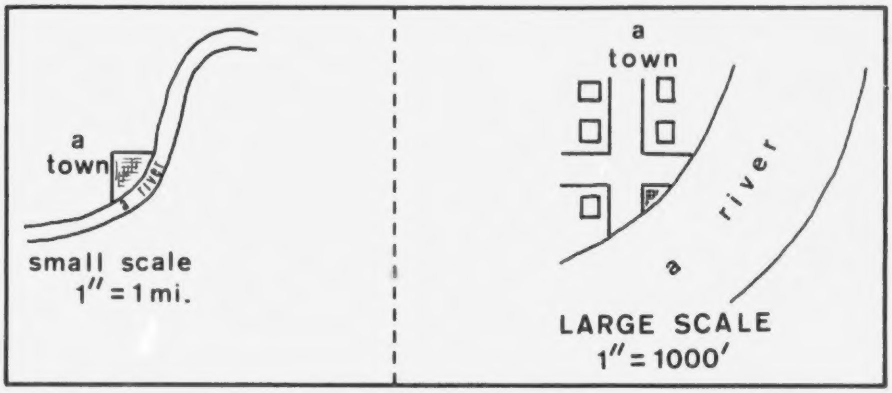


Figure 6.8. Compares a small scale map to a large scale map of the same area.

1. Graphic scale: Of the three ways scale can be represented, graphic scale is the first we will discuss. This is a line which is divided into parts marked to represent distances on the earth. (See Figure 6.9)

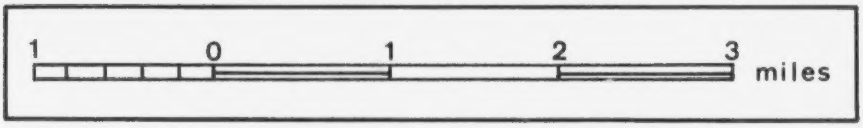


Figure 6.9. An illustration of a graphic scale. The distance from 0 to 1 represents 1 mile on the ground; 0 to 2 represents 2 miles.

2. Proportional scale: This is a scale in which numbers are used in fraction or ratio form; one number represents a unit of measurement on the map, and the other number gives the actual measurement of distance on the earth's surface that is represented on the map. For example, 1:62,500 or 1/62,500 means that one unit of measurement on the map represents 62,500 of the same units on the earth's surface.
3. Verbal scale: This approach spells out the scale in words, such as "one inch (on the map) equals one mile (on the ground)." This is done simply by measuring the graphic scale with a ruler (0 to 1 mile is 1 inch) or by converting the fractional scale units of distance (1:24,000 means 1 inch on the map equals 24,000 inches on the earth's surface, or 1 inch equals 2,000 feet.).

SEE ACTIVITY 6.5

C. Distances: Distances on the map can be determined in the following way. First, transfer to a piece of paper the distance between two points on a map. Next, place the marked-off paper above or below the graphic scale on the map. (See Figure 6.10)

SEE ACTIVITY 6.4

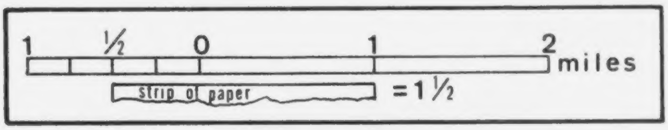


Figure 6.10. The fractions on the left of the 0 measure divisions of 1 mile. By placing a marked off distance below the scale, the represented distance can be determined.

D. Colors: Many maps are different colors to denote specific kinds of features. Examples include blue for water and shades of brown for elevation. The color code is usually found in the map legend (an explanation of symbols is patterns used on a map).

E. Symbols: In addition to colors, most maps use symbols to represent cultural and natural features. As with the color code, symbols should be noted in the map legend.

F. Locations: To effectively use a map, it is necessary to pinpoint the locations of various features. In addition to locating the feature, you should also be able to communicate descriptions of locations to others so they can locate that specific feature.

  1. Area descriptions: These include general descriptions of a region rather than a specific point.

    a) Distance and direction: Also known as metes and bounds, this type of area description gives the direction and length of a boundary line of a given area beginning with a starting point, continuing around the margin of the area, and returning to the starting point. Usually, landmarks such as rivers, trees, and hills are used as reference points. The following is an example of an area description using distance and direction: Beginning at the river bridge, go upstream 80 paces, west 104 paces to the large oak tree. Turn south, taking 80 paces to the crest of the hill; proceed back to the river bridge. Think of some problems you can foresee using this type of description.

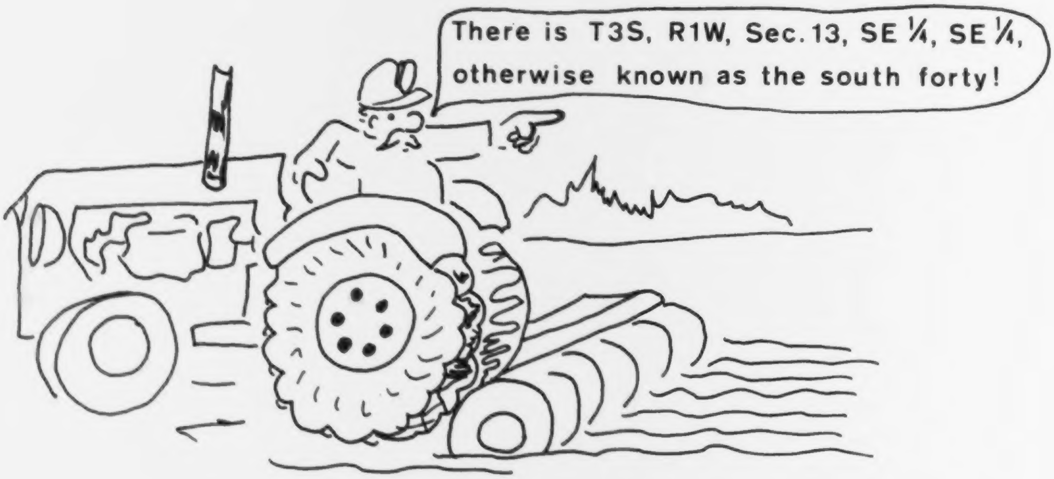
SEE ACTIVITY 6.7

Some of the following material on the topics of location and topographic maps has been adapted from the ISGS publication *Guide to the Use of Illinois Topographic Maps*.

    b) Township and range: In 1785, a rectangular system of land survey was adopted for dividing all newly settled territory of the United States. By this system, commonly referred to as the township and range system, 29 states in the central and western United States have been divided into a network of township six miles square, or 36 square miles in area. Reference lines, called base lines and principal meridians, were established for the unmapped territory.

(1) Township and range organization: The top and bottom boundaries of a township (those lines going east and west) are called township lines; the east and west boundaries (those lines going north and south) are called range lines. Starting from the intersection of a base line and a principal meridian, the strips of territory between township lines were numbered consecutively toward the north and south; the strips of territory between range lines were numbered consecutively toward the east and west. (See Figures 6.11 and 6.12) Therefore, each township is designated by two numbers, a township number and a range number. For example, the first township north and east of the intersection of a base line and a principal meridian is designated as Township 1 North, Range 1 East. In practice, this designation is abbreviated as T. 1N., R. 1 E. Farther northward, the townships are designated T. 2 N., R. 1 E.; T. 3 N., R. 1 E.; and so forth.

SEE ACTIVITY 6.8


There is T3S, R1W, Sec. 13, SE ¼, SE ¼, otherwise known as the south forty!

(2) Section organization: The township and range system permits the accurate identification of most parcels of land in Illinois. In the early 1800's, each normal township was divided to the best of the surveyor's ability into 36 sections, each section being one mile square and containing 640 acres. The sections are numbered as illustrated in Figure 6.11. The sections can be subdivided to provide more exact area locations. The subdivision is usually by quarters; thus, location A is the southeast quarter of the northeast quarter of Section 13, Township 3 South, Range 1 West. This is written as follows: T3S, R1W, Sec. 13, NE 1/4, SE 1/4. What is the location of B?

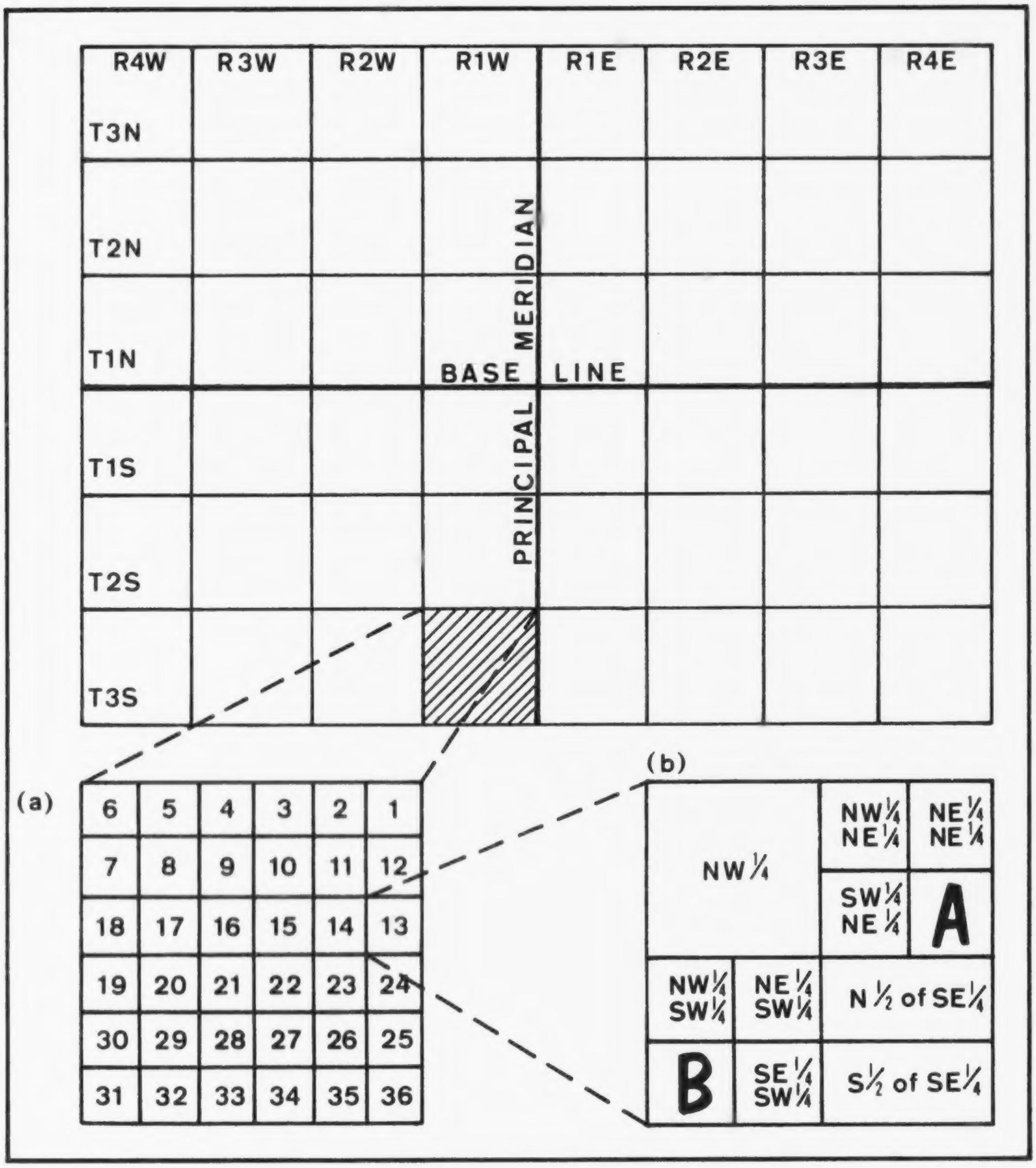

R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
T3N
T2N
T1N
T1S
T2S
T3S
PRINCIPAL MERIDIAN
BASE LINE
(a)
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
(b)
NW¼
NW¼ NE¼
NE¼ NE¼
SW¼ NE¼
A
NW¼ SW¼
NE¼ SW¼
N½ of SE¼
B
SE¼ SW¼
S½ of SE¼

Figure 6.11. An illustration of township and range organization. (a) is an enlargement of a township. (b) is an enlargement of a section.

Some discontinuities and interruptions will be noted in the grid system in Illinois. These are the result of land grants dating from the French colonization and old Indian treaty boundaries that were honored when the grid system was established.

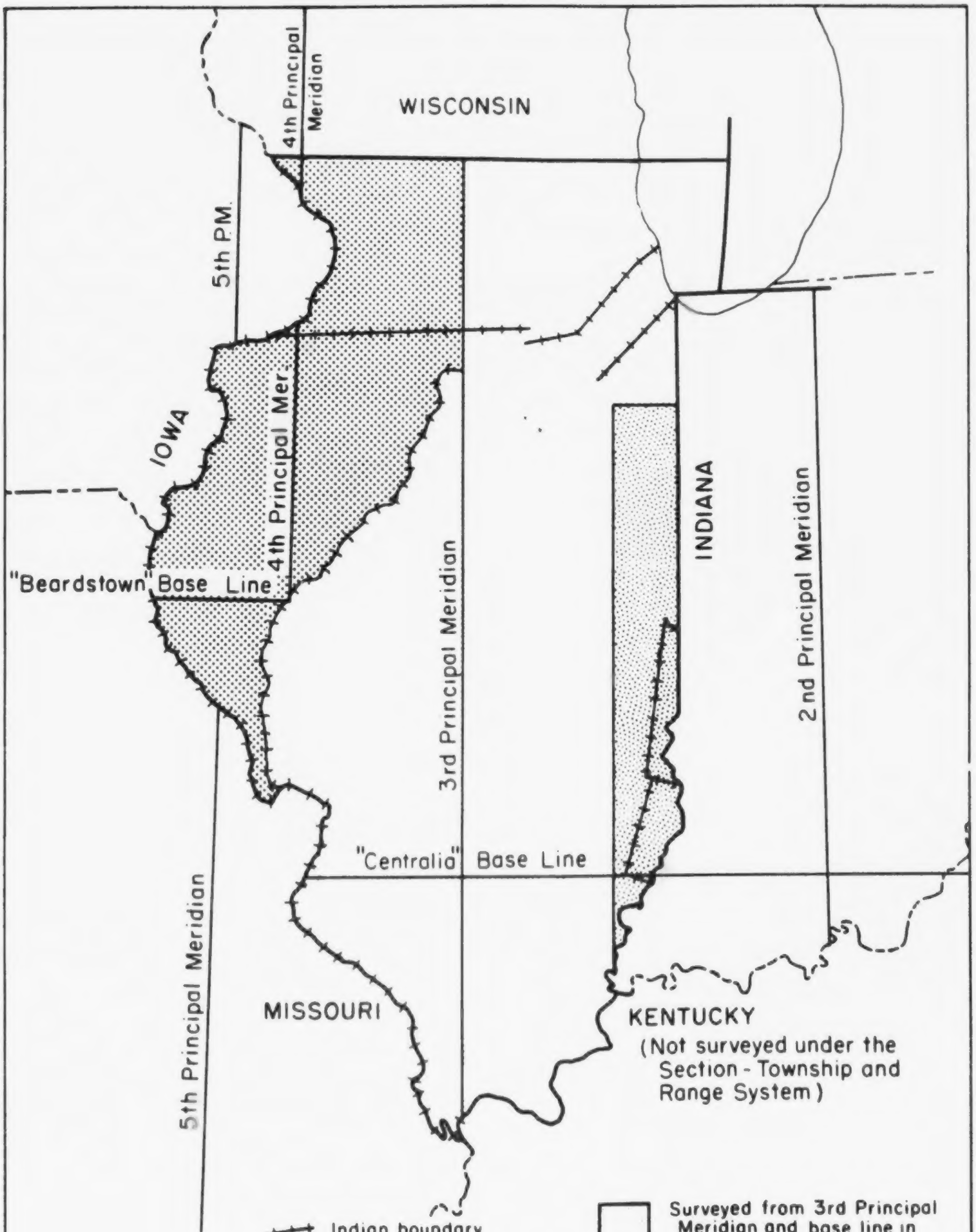

4th Principal Meridian
WISCONSIN
5th P.M.
IOWA
4th Principal Mer.
"Beardstown" Base Line
3rd Principal Meridian
INDIANA
2nd Principal Meridian
"Centralia" Base Line
5th Principal Meridian
MISSOURI
KENTUCKY
(Not surveyed under the Section - Township and Range System)
Indian boundary
Surveyed from 3rd Principal Meridian and base line in southern Illinois
Surveyed from 2nd Principal Meridian and base line in southern Indiana
Surveyed from 4th Principal Meridian and base line in western Illinois
0
25
50
75
100 miles

Figure 6.12. Principal meridians and base lines of Illinois and surrounding states (ISGS)

(See Figure 6.13) The old lands grants are found mainly along Wabash and Mississippi Rivers in southern Illinois, because these rivers were the main travel and trade routes along which settlement first occurred.

SEE ACTIVITY 6.7

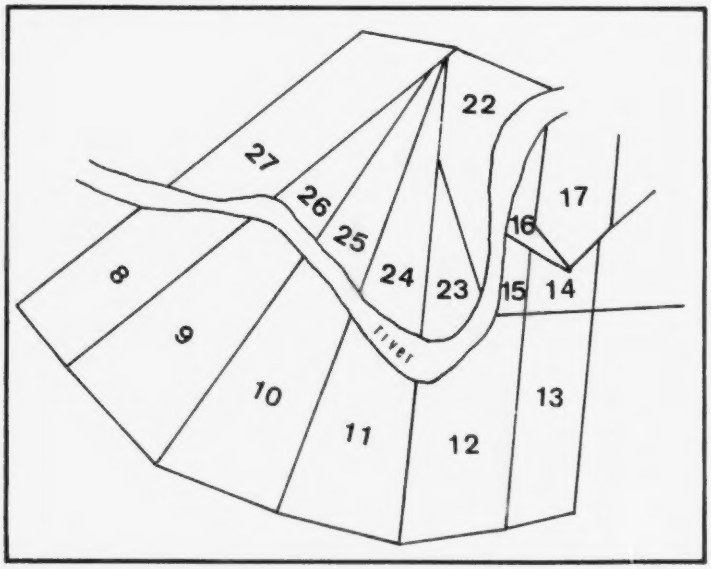


Figure 6.13. An example of old land grants found along the Mississippi River.

2. Other descriptions: These include descriptions of very specific points and places.
    a) Physical landmarks: The physical landmark method is used not only as a point of orientation for the map follower but also as the point of origin for the distance and direction system of location discussed earlier. In other words, a feature can be located on a map by its distance and compass direction, or angle, from another fixed location. The standard practice is to state the compass direction with the reference to the four principal points--north, east, south, and west. Compass directions are commonly expressed as a measured number of degrees (up to 90°) east or west of north, or east or west of south. (See Figure 6.14) In reports, compass directions are abbreviated as N. 10 E. (10 degrees east of north), S. 60 W., and so forth. The accuracy of the landmark's location is limited, depending upon the size of the object--that is, a town shown as a point on a map will be less precise than a surveyor's marker. Because of the great amount of area to be covered on a comparatively small piece of paper, it is helpful to remember that the width of an average pencil line on a 15-minute map represents a strip approximately 100 feet wide on the ground.

SEE ACTIVITY 6.10

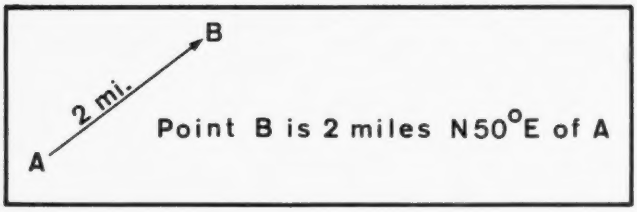


Figure 6.14. A point description of a physical landmark.

b) Latitude and longitude: Every point on the earth's surface has a unique location with respect to latitude and longitude. In this system, locations are expressed in terms of degrees north or south of the equator and east or west of the Prime Median. Accuracy may be increased by dividing each degree into 60 minutes and each minute into 60 seconds. The larger the map scale, the more accurate the location. For review of latitude and longitude, refer to Chapter 2.

SEE ACTIVITY 6.11

c) Plane coordinate: This type of description involves developing a grid (a series of east-west, north-south lines) in which a combination of letters and/or numbers is used to locate points. (See Figure 6.15) Several grids are used, including one developed for your use later. These will be discussed in more detail later.

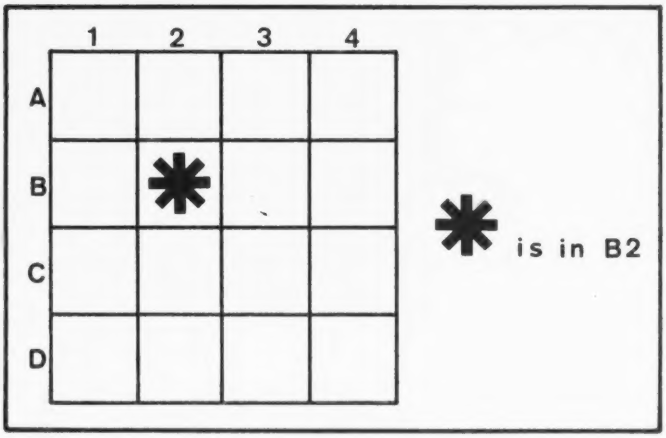


Figure 6.15. A description using plane coordinates.

G. Odds and ends: These include miscellaneous items that can be essential.
   1. Right side up: How do you know you have your map right? Read some of the words! (See Figure 6.16)

Figure 6.16. George experiences problems in map reading.

2. Folding: Many maps, such as highway maps, require folding. To refold maps, simply attempt to do so a few times. If the map still looks funny, sit on it! Most maps used in geology are rolled or flat. (In truth, geologists simply never learned to fold them!)

SEE ACTIVITY 6.12

VI. Topographic maps: Topographic maps show the shape of the land surface (topography) by a system of elevation lines called contour lines. In other words, topographic maps portray the high areas, the low areas, the flat areas, and the hills and valleys. They show surface waters such as rivers, lakes, and swamps. In addition, they include such man-made features as canals, dams, roads, railroads, houses, and factories.

A. Contour lines: These are lines drawn on a map that represents points of equal elevation. The shoreline of a quiet pond or lake is, in effect, the same as a contour line.

1. Purpose of contour lines: These lines add the third dimension of height to a two-dimensional map. Once you learn to visualize what they represent, they can be quite useful.
2. Understanding contour lines: These are several rules that will aid you in interpreting topographic lines.

a) Elevation: Elevation is shown by contour lines which connect all points of the same elevation above the mean sea level (the average height of the sea). (See Figure 6.17)

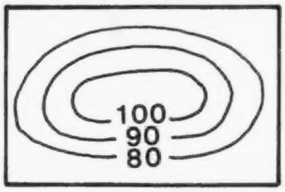


Figure 6.17. All points on each line are the same elevation.

b) Crossing: Contour lines never cross; this would indicate two different elevations at one point. Anything on a 100-foot contour line must be 100 feet above sea level. (See Figure 6.18)

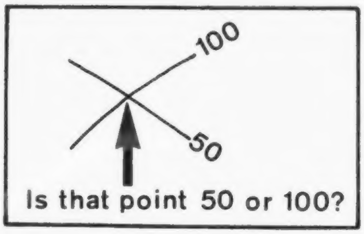


Figure 6.18. Contour lines do not cross.

c) Contour interval: The vertical distance or distance in elevation between contour lines that are next to each other is called the contour interval. The contour interval depends upon the scale of the map, the amount of relief (difference in elevation between highest and lowest points), and the degree of precision required. (See Figure 6.19) Would the same contour interval be used for the Grand Canyon region as that used on a map of flatter Illinois? The contour interval is always the same on given maps, so there would never be ten feet of difference between two lines at one point and 20 feet of difference at another point. When the relief is low (when the land is relatively flat), as in most scenic Illinois, the contour interval is usually ten or 20 feet. In flat areas such as wide river valleys or flat uplands, a contour interval of five feet or less is used. In rugged mountainous regions (of high relief), a contour interval of as much as 50 or 100 feet may be used. Why do you think it is important to use different contour intervals?

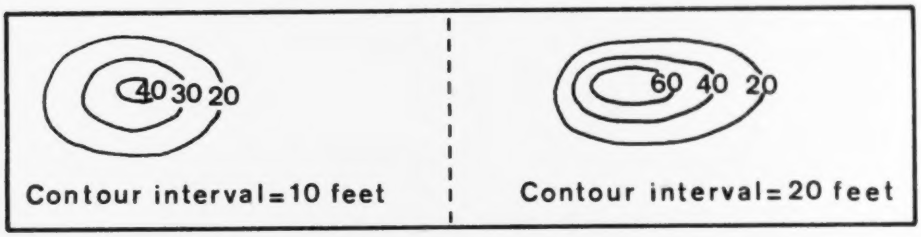

40 30 20
Contour interval=10 feet
60 40 20
Contour interval=20 feet

Figure 6.19. The vertical distance between each contour is called the contour interval.

d) Spacing: The spacing of contour lines indicates the degree of slope. Widely-spaced lines indicate a gentle slope, while close-spaced lines indicate a steep slope. Equally-spaced contours depict a uniform slope. Cliffs are shown by contour lines that coincide. (See Figure 6.20.)

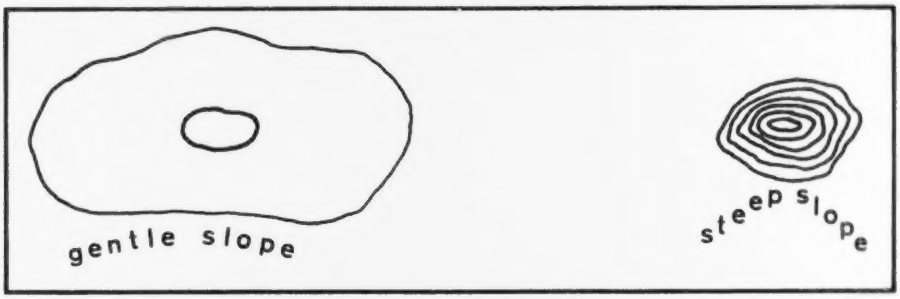

gentle slope
steep slope

Figure 6.20. Widely-spaced contour lines indicate a gentle slope. Closely-spaced contour lines indicate a steep slope.

e) Shape: The shape of contour lines gives an indication of the shape of the land. Straight or gently-curved contour lines indicate a fairly regular surface, with wiggly lines indicating an irregular surface. (See Figure 6.21)

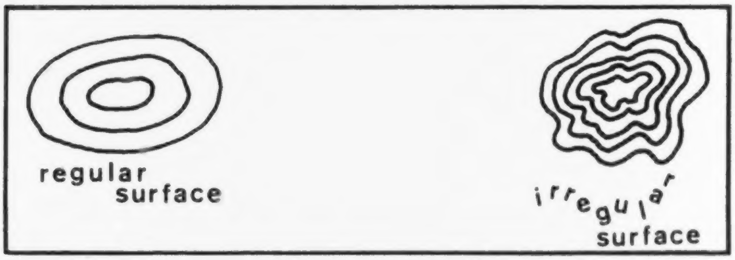

regular surface
irregular surface

Figure 6.21. Smooth contour lines represent a regular surface, while wiggly lines portray an irregular surface.

f) Closed loops: Contour lines which form closed loops indicate hilltops. The top of the hill is generally higher than the highest closed contour. (See Figure 6.22) It might be added here that all contour lines close on themselves at some point, but usually the small area covered on a map does not include enough coverage of the area to show the contour lines closing. Thus, most do not close within the limits of that particular map.

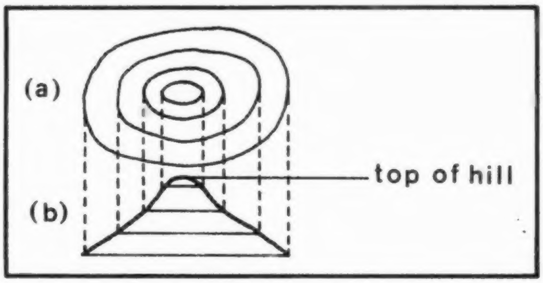


Figure 6.22. (a) is an aerial view of a hill; (b) is a side view. The smallest loop in the center represents a hilltop.

g) Depressions: A depression (a sunken area) is indicated by a closed contour line with hachure lines (small lines drawn at right angles to the contour line). The first depression contour is read as the same elevation as the preceding contour that encloses it. Each successive depression contour is lower than the one that enclosed it. (See Figure 6.23)

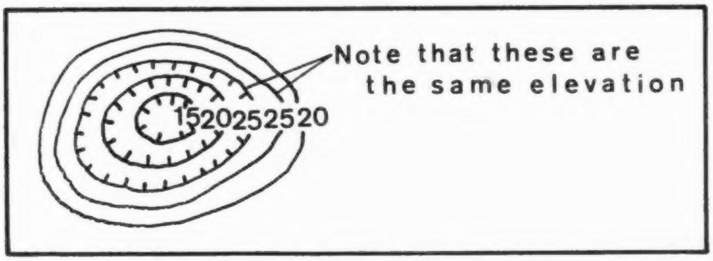


Figure 6.23. Depressions are indicated by the hachure lines. The first depression contour is the same elevation as the regular contour that surrounds it.

George and Webster define DEPRESSION

de.pres.sion, n. 3. a sunken place. 5. psychiatry, a great sadness.

Hole
gloom
despair
agony

h) V-shaped contour lines: In stream valleys, contour lines point upstream or upvalley. In other words, the contours form V's that point upstream. In the upstream direction, the successive contours represent higher elevations. (See Figure 6.24) For example, if one were standing on a stream bank and wished to get to the point at the same elevation directly opposite him on the other bank, without stepping up or down, he would need to walk upstream along the contour at that elevation to where it crosses the stream bed, cross the stream, and then walk back downstream along the same contour.

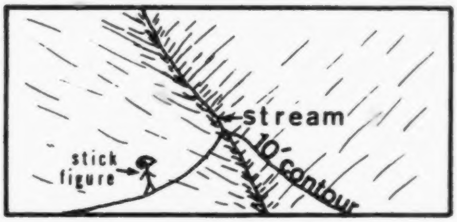


Figure 6.24. Contour V's point upstream. The sturdy stick figure is following the ten-foot contour line from one side of the stream to the other to illustrate how the contour lines V. We wish to thank him/her for his/her cooperation.

i) Highest and lowest points: Neither the top of a hill nor the bottom of a valley is ever shown by a single contour line. (See Figure 6.25) For example, if one were to walk to the top of a mountain, he would cross the highest contour before reaching the summit, and he would cross the same contour again on the way down the other side. Similarly, if one were to make a traverse down the side of a valley to a stream and up the other side, he would cross a given contour on the way down and would cross the same contour on the way up the other side. The stream would flow at an elevation lower than the elevation of the contour line nearest the stream.

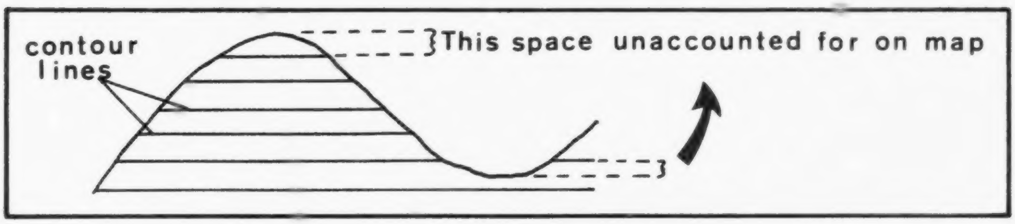


Figure 6.25. This is a cross-section of a hill and valley with contour lines drawn on them to illustrate why the highest and lowest points are not necessarily shown on a contour map.

j) Index contours: Every fourth or fifth contour line is called an index contour. It is darker than the other contours and is labeled with numbers (unlike the other contours) to show the elevation represented. (See Figure 6.26)

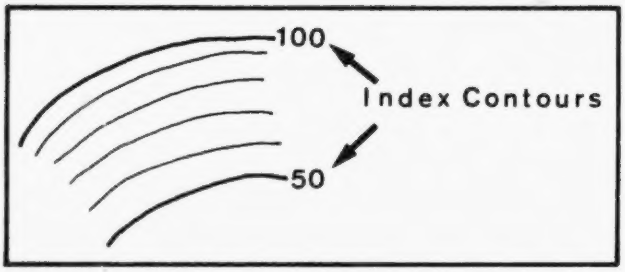


Figure 6.26. The darker labeled contours are called index contours. By knowing the contour interval, ten in this illustration, you can determine the elevation represented by the unlabeled contours.

k) Vertical control points: Specific elevations at points between contour lines are represented in two ways.

(1) Bench marks: The specific elevation of selected points is determined in the field by employees of the USGS. These permanent control points are usually marked on the ground by metal tablets 3 3/4 inches in diameter set in rock or masonry and are called bench marks. They are represented on topographic maps by an X with the letters "BM" and the exact elevation next to them. (See Figure 6.27)

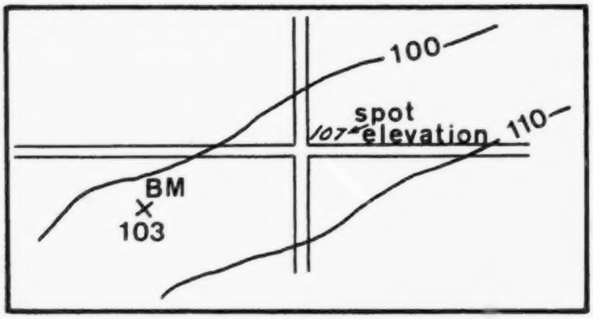
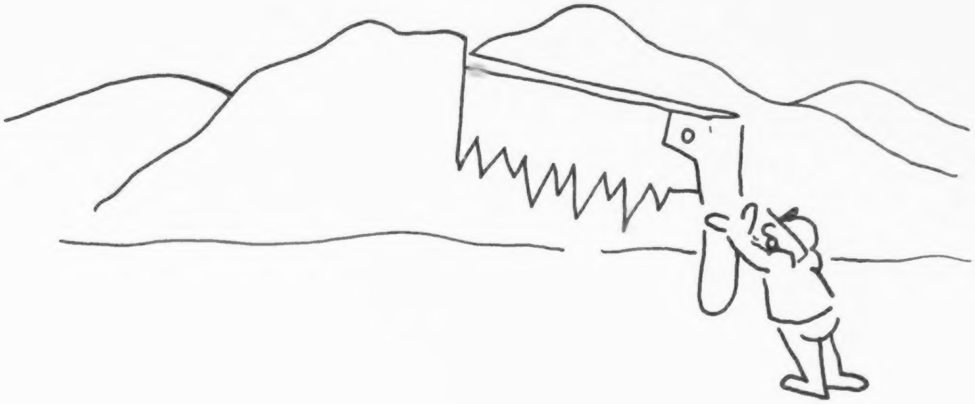


Figure 6.27. This shows two ways of giving exact elevations between contours.

(2) Spot elevations: Spot elevations between contours are given at many locations, such as road intersections, hill summits, and lake surfaces. Spot elevations differ from control elevation stations, such as bench marks, in not being established by permanent markers. Spot elevations are shown by italicized (slanted) numbers on topographic maps, but established bench marks are given as vertical numbers. (See Figure 6.27)

SEE ACTIVITY 6.13

B. Topographic map profiles or cross-sections: Sometimes it is useful to show the shape of the land surface (or topography) along a line in a certain direction. By constructing a topographic profile or cross-section like the one shown in Figure 6.29, an edge view of the land surface is obtained as though the earth had been sliced and one were looking at the slice from the side. One can also think of the profile line as the intersection of an imaginary vertical plane with the land surface.



1. Construction of a profile or cross-section: A profile can be prepared in the following way. (See Figures 6.28, 6.29, and 6.30)
   - a) Straight line drawn: The edge of a piece of paper is placed along the line from X to Y. On the top edge of the paper, make a short line for every contour line crossed. Label the elevation of each mark. X and Y are marked with their estimated elevations, in addition to the stream positions.
   - b) Points marked: The points marked on the edge of the paper are transferred to a sheet of ruled paper. (Graph paper can be used.) The maximum relief between X and Y is found to be about 60 feet, in this case. The ruled lines are numbered vertically 20, 30, 40, and so on, corresponding to the contour interval on the map.
   - c) Elevations plotted: The elevations are then plotted on the ruled paper by drawing vertical lines from the points down to their corresponding elevations.
   - d) Final profile or cross-section completed: The elevation points are then connected by a smooth line. The resulting profile or cross-section line shows the topography along line XY.
2. Labeling: A topographic profile would always be completely labeled. The end points should be marked, and their locations given. All features such as streams and towns should be labeled. The profile also should have a title or caption. Most important of all, the scale of the profile should be stated.
3. Scale: Note that the profile will have two scales: a horizontal scale and a vertical scale. The horizontal scale is the map scale. The vertical scale may also be the map scale, or it may be larger. If both the horizontal scale and the vertical scale of the profile are the same, the profile is said to be drawn to "natural scale." Figure 6.29 shows a topographic profile drawn between points X and Y in Figure 6.28 using natural scale The scale of the map in Figure 6.28 is 1 inch = 2,500 feet. The graph paper used has ten divisions per inch, one division representing 250 feet with no vertical exaggeration.

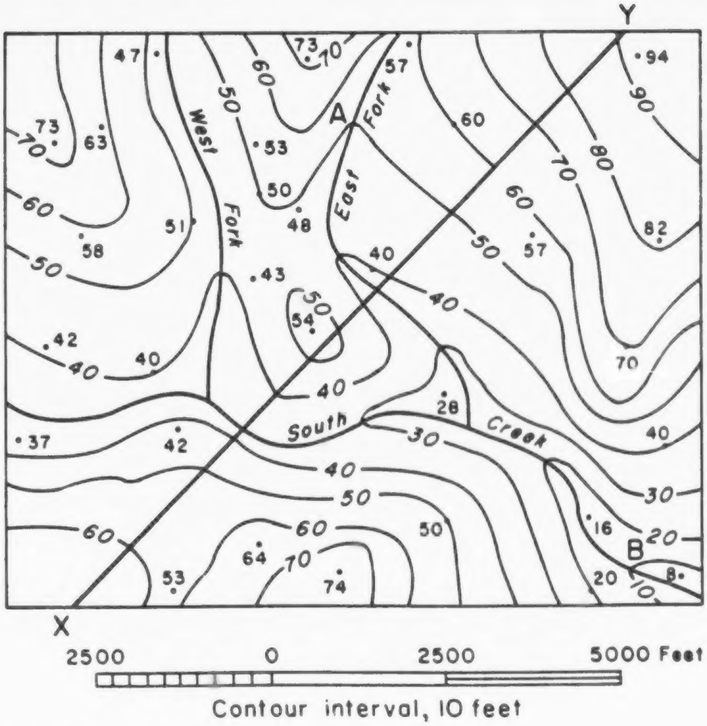

X
Y
A
B
West Fork
East Fork
South Creek
94
90
80
70
60
50
40
30
20
10
73
47
57
63
53
48
51
58
43
54
42
37
28
82
16
8
64
74
2500
0
2500
5000 Feet
Contour interval, 10 feet

Figure 6.28. Contour map showing control points. (ISGS)

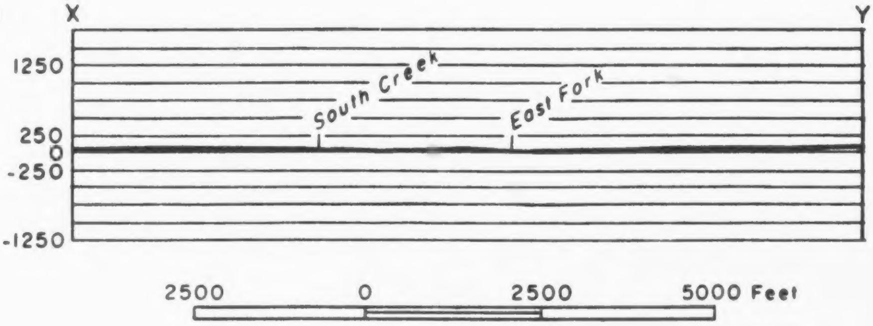


Figure 6.29. Profile from X to Y in Figure 6.28 drawn at natural scale.

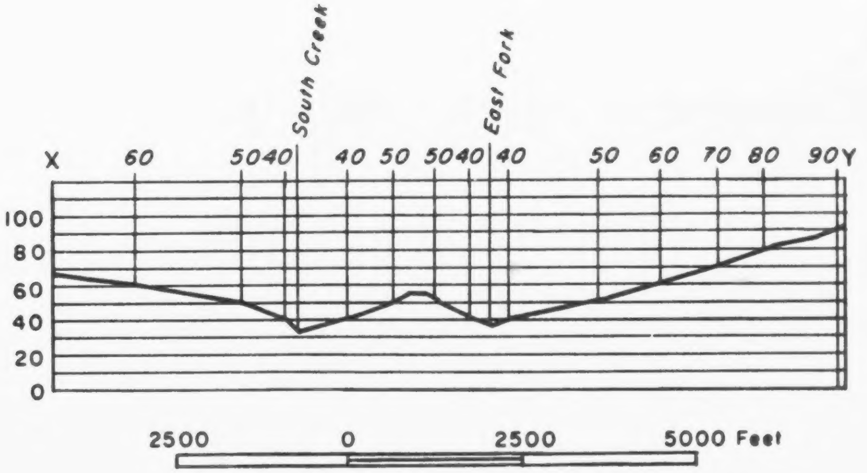


Figure 6.30. Profile from X to Y in Figure 6.28 drawn with a vertical exaggeration of 25 times.

Since the maximum relief along the line of the profile is only 60 feet, the hills and valleys barely show up on the completed profile. In most cases, it is desirable to increase the vertical scale. The vertical scale is then said to be "exaggerated." The profile shown in Figure 6.30 is the same as that in Figure 6.29 but has a vertical exaggeration of 25. In this case, one inch on graph paper equals 100 feet, and each division equals ten feet.

$$\text{Vertical exaggeration} = \frac{\text{Horizontal scale (map scale)}}{\text{Vertical scale}}$$

$$= \frac{\text{2,500 feet per inch}}{\text{100 feet per inch}}$$

$$= 25$$

SEE ACTIVITY 6.14

4. Determining gradients: The gradient is the slope or rate of change in elevation for a given distance.
   a) Gradient of a slope: The average gradient of a land surface can be determined from a topographic map. This information is useful for such projects as planning roadways or for soil conservation programs. To determine the average slope between two points, first measure the straight line distance in miles between two profiles. Then using the contour lines, determine the difference in elevation (vertical distance) in feet between the two points. The gradient is then calculated using the following formula:

$$\text{Gradient} = \frac{\text{Difference in elevation between two points}}{\text{Straight line distance between two points}}$$

The gradient is expressed in feet per mile. Example: The distance between points A and B in Figure 6.28 is 1.42 miles. The difference in elevation between the points is 40 feet.

$$\text{Gradient} = \frac{\text{40 feet}}{\text{1.42 miles}} = \text{28.2 feet per mile}$$

The gradient can also be expressed as a ratio, or as a percentage. In this case, the distance used in the formula must also be in feet.

$$\text{Percentage gradient} = \frac{\text{40 feet}}{\text{1.61 miles}} = \times 100 = .0053 \times 100 = 0.53\%$$

SEE ACTIVITY 6.15

   b) Gradient of a stream: The gradient of a stream is determined in about the same way as the gradient of a slope. The distance between two points on a stream is not measured in a straight line but along the course of the stream. This can easily be accomplished by laying a string along the stream course or by carefully measuring it in short segments. Example: The distance from A to B along East Fork in Figure 6.28 is 1.61 miles. The difference in elevation is 40 feet.

$$\text{Steam gradient} = \frac{\text{40 feet}}{\text{1.61 miles}} = \text{24.8 feet per mile}$$

C. USGS topographic maps: The United States Geological Survey (USGS) is the source for almost all topographic maps in the United States. While some of the following information may be repetitious, it establishes the standards used for all USGS topographic maps.

1. Map sizes: For most topographic maps published by the USGA, the area of land depicted is a quadrangle (an area with four sides and four angles) bounded by parallels of latitude and meridians of longitude. Quadrangles covering an area of 7.5 minutes of latitude and longitude are published at the scale of 1:24,000 (1 inch = 2,000 feet, United States System) or 1:25,000 (1 centimeter = 250 meters, Metric System). Quadrangles covering an area of 15 minutes of latitude and longitude are published at the scale of 1:62,500 (1 inch = approximately 1 mile). Most of the U.S. is mapped in the 15-minute series. Depending upon its latitude, each of the 289 quadrangles in this series covers from about 220 to nearly 238 square miles. Many parts of the U.S. are also mapped in the 7.5-minute series, each map covering one-fourth of a 15-minute quadrangle. The area covered by a 7.5-minute map ranges from approximately 55 to 59 square miles. Periodically, the 7.5-minute maps are revised primarily to show cultural changes. This is accomplished by the use of aerial photographs, and the changes are indicated on the revised maps by purple overprint.
2. Map orientation: On quadrangle topographic maps published by the USGS, north is toward the top of the map, and east is toward the right. The top and bottom map boundaries are parallels of latitude, and the right and left boundaries are meridians of longitude. In addition to outlining the mapped area, these boundaries also locate the position of the area on the earth's surface, because parallels of latitude and meridians of longitude form the earth's coordinate system. Meridians are oriented toward geographic north (true north), not magnetic north (the direction in which a compass needle points). The angular difference between true north and magnetic north is called magnetic declination. (See Figure 6.31) True north, magnetic north, and magnetic declination are usually given in the lower margin of a quadrangle topographic map. When working in the field with topographic maps, a geologist uses true north as the principal reference direction. He must compensate his compass readings by the amount of magnetic declination for the area in which he is located, in order to plot information on the map in terms of true north.

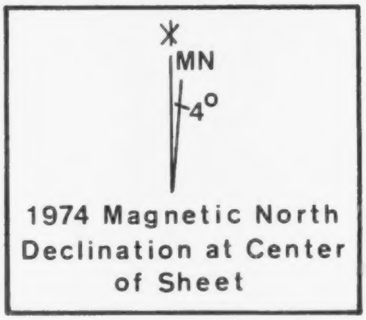


Figure 6.31. This illustration of magnetic declination is much the same as that found on all USGS topographic maps.

3. Map margins: The margins of USGS topographic maps contain much more useful information. The name of the mapped quadrangle, taken from a city, town, or prominent natural feature within its boundaries, is given in the map margins as are the names of adjoining quadrangles. The marginal information tells briefly when the map was made, what projection was used, where the quadrangle is located, and what agency prepared the map. In addition, it provides other facts helpful to the user, such as mileage distances or major highways, the latitude and longitude of the map, the size of the map, and the contour interval. Sometimes a legend can also be included in the map origin.
4. Location techniques: Several systems are commonly used in locating areas or points on topographic maps.
   a) Township and range: This system can be used in many states. On USGS topographic maps, the townships and ranges are printed in red or black along the map boundaries. The section lines are shown and numbered in red. One problem students sometimes have with locating areas on a topographic map is that they do not divide the townships and ranges properly. Remember, the map boundaries are determined by longitude and latitude, so townships and ranges may overlap map boundaries.

SEE ACTIVITY 6.16

   b) Latitude and longitude: Occasionally, latitude and longitude may be used for location. However, since it is difficult to subdivide seconds of measurement of large-scale maps, it is not often used.
   c) Grid systems: Making a grid system on the map surface is another useful technique in map location.
      (1) Latitude and longitude grid: This method is also known as the rectangular system. USGS topographic maps are usually divided into three equal parts of latitude and longitude thus giving nine equal rectangles. The rectangles are then subdivided by compass direction. (See Figure 6.32)

SEE ACTIVITY 6.17

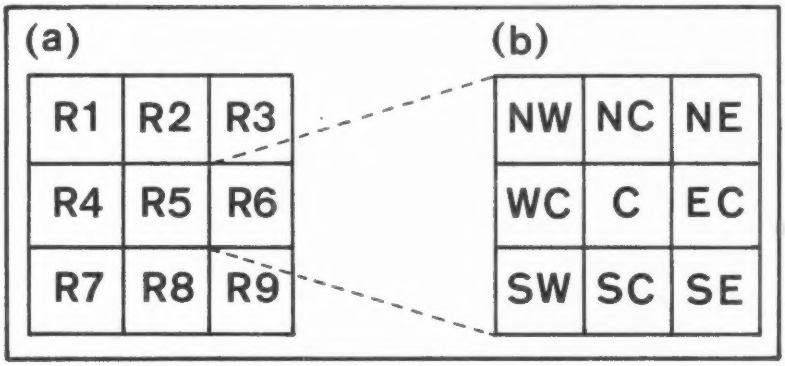


Figure 6.32. (a) illustrates the rectangular numbering system. (b) is an enlargement of *one* rectangle. The letters are abbreviated as the following: N is north, S is south, E is east, W is west, and C is central.

(2) Letter and number grid: In situations where topographic maps have been reproduced in part, such as *100 Topographic Maps*, published by Hubbard Press, a grid system based on a combination of letters and numbers may be used. (See Figure 6.33)

SEE ACTIVITY 6.18

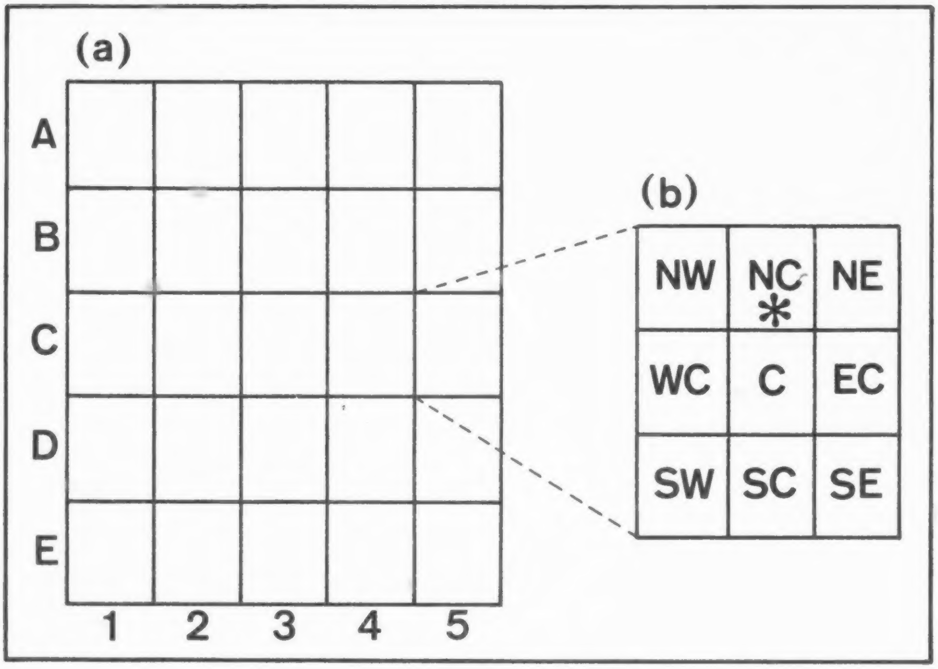


Figure 6.33. (a) illustrates the grid used in *100 Topographic Maps*. (b) illustrates the divisions to be used within each rectangle. The star is in C5, NC.

5. Scales and distances: As you recall, scale is the comparison between actual distance on the earth's surface and the same distance represented on a map.
   a) Proportional scale: The 15-minute topographic map, with a proportional scale of 1:62,500, is slightly less than one inch to the mile. If the map were actually one inch to the mile, the proportional scale would be 1:63,360. However, the difference of 860 inches or 71.6 feet per mile between the two scales is only about the width of a fine pencil line on the map. A map of this scale cannot show as many details of culture and topography as does the 1:24,000 scale map because the 1:62,500 scale map presents four times more ground area on a somewhat smaller map sheet. In other words, the larger the scale (large-scale map), the more detail that can be shown on a map. Large-scale maps are useful for highly developed areas or rural areas where detailed information is needed for engineering purposes. Medium-scale maps are used for rural areas where less detail is necessary. Small-scale maps are useful in the study of extensive projects or for regional planning.
   b) Graphic scale: In addition to the notations of the proportional scale, topographic maps have a graphic, or bar, scale along the map margin. (See Figure 6.34) The graphic scale consists of a bar that is divided into equal segments, each of which represents an equal distance on the map. The first segment on the left of the bar scale usually is divided into smaller equal units to make it easier to get a more accurate measurement of fractional unit distances. The bar scale is convenient when the user does not have a ruler or measuring scale. The map distance between two points can be transferred to the edge of a card or paper which can then be used to make distance measurements on the bar scale.

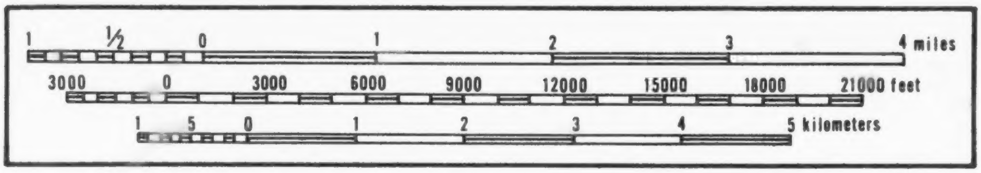


Figure 6.34. Scales from a topographic map from *Guide to the Use of Illinois Topographic Maps*, ISGS.

6. Symbols and colors: A unique system of symbols and colors, a graphic language, has been devised to illustrate features on topographic maps. Some of the more common symbols and colors are as follows:
   a) Blue: Water features are shown in blue.
   b) Black: Cultural features, such as buildings, some roads, railroads, and some political boundaries are shown in black.
   c) Red tint: Incorporated areas are shown in red tint.
   d) Red: Section lines, section numbers, township (T and R) classification, and heavy-duty roads are shown in red.
   e) Green: Not all editions of topographic maps contain green, but those which do signify wooded areas.
   f) Purple: Maps are revised periodically, usually by plotting data obtained from aerial photographs. Such revisions are shaded purple.
   g) Brown: The predominant feature of the topographic quadrangle is topography. Contour lines, those little brown squiggly lines on the map, and the index contour numbers are shown in brown.

Some symbols (pictographs) resemble the objects they represent, for example, churches, schools, or railroads. A single-page chart, "Map Symbols," is available from the USGS. (A copy of this can also be found on page 10 of *100 Topographic Maps.*)

SEE ACTIVITY 6.19

7. Contour lines: Topography refers to the shape of the land surface. On USGS topographic maps, topography is shown by a series of brown lines, called contour lines. The contour interval is given at the bottom of USGS maps. Refer to section VI. A. of this chapter for a review of contour lines.

SEE ACTIVITY 6.20

8. Map profiles or cross-sections: Profiles from USGS topographic maps are done in the same manner as in section VI. B. of this chapter. Usually index contours are used as crossing points from which the profile is drawn. By now, however, you should be familiar enough with contour lines to sketch general topographic relief, such as valleys, hills, and flat land.

SEE ACTIVITY 6.21

D. Uses for topographic maps: We are primarily interested in topographic maps as a tool in geology, but there are many other uses. These include planning airports, highways, dams, pipelines, transmission lines, industrial plants, and countless other types of construction. They also aid in the study and application of flood control, soil conservation, and reforestation. In addition, those in pursuit of outdoor activities such as hunting, fishing, and vacationing have discovered the advantages of topographic maps. To the serious hiker, reliable maps showing relief features, woods, clearings, and watercourses are of extreme value.

SEE ACTIVITY 6.22

VII. Geologic maps: Beneath all of us, if we dig deep enough, is rock. Geologic maps show the rock layers that are present beneath the soils and vegetation on the earth's surface as if they had been scraped off the rock layers. These maps show distribution of rock formations and relative ages, kind of bedrock, differences between rock layers, arrangement of layers (faults and folds), thickness of layers, and geologic history. They are a method of recording and presenting data in a compact and systematic form.

GEOLOGIC MAP

A. Making a geologic map: The procedure involved in making a geologic map involves several steps.

1. Observation and recording: The area to be mapped is walked by the geologist. Usually, his base map, a basic map that shows roads, streams, and houses, is a USGS topographic map. As he walks the area, he observes and records exact locations and information about rock outcrops in the area. Sometimes, well logs (records from drilling operations) are used to study deeper unexposed rocks. The kinds of information gathered include rock type, color, fossils present, strike (directional trend of the outcrop on the surface) of the rock, and the rock dip (slope of layers of an outcrop away from the horizon). (See Figure 6.35)

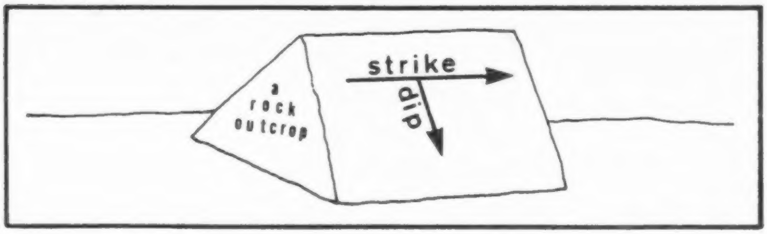


Figure 6.35. An illustration of strike and dip.

2. Plotting on a base map: From field data, the information is plotted on a base map. Symbols indicate the rock type, age, and strike and dip symbols (These are used to show the direction and amount of strike and dip.) Therefore, a strike and dip symbol like the one in Figure 6.36 could indicate a northeast-southwest strike and a southeast dip direction of 30 degrees.

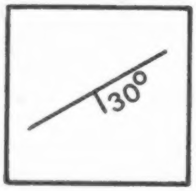


Figure 6.36. The long line is the strike line, and the short perpendicular line is the dip line.

3. Drawing rock boundaries: Finally, the boundaries of the rock units are drawn, and colors are added to show different units and their ages. Usually, a legend and vertical rock column (vertical chart showing relative rock ages and thicknesses) are added to aid the geologist.

B. Identifying rock structures: Many rock structures can be identified by observing the outcrop patterns. In addition, this information can be used to draw geologic cross-sections of the geologic map areas. (See Figures 6.37 and 6.38)

1. Observing outcrop patterns: Using the shape of the rock outcrops and the strike and dip information, basic rock structures can be identified. (See Figure 6.37)

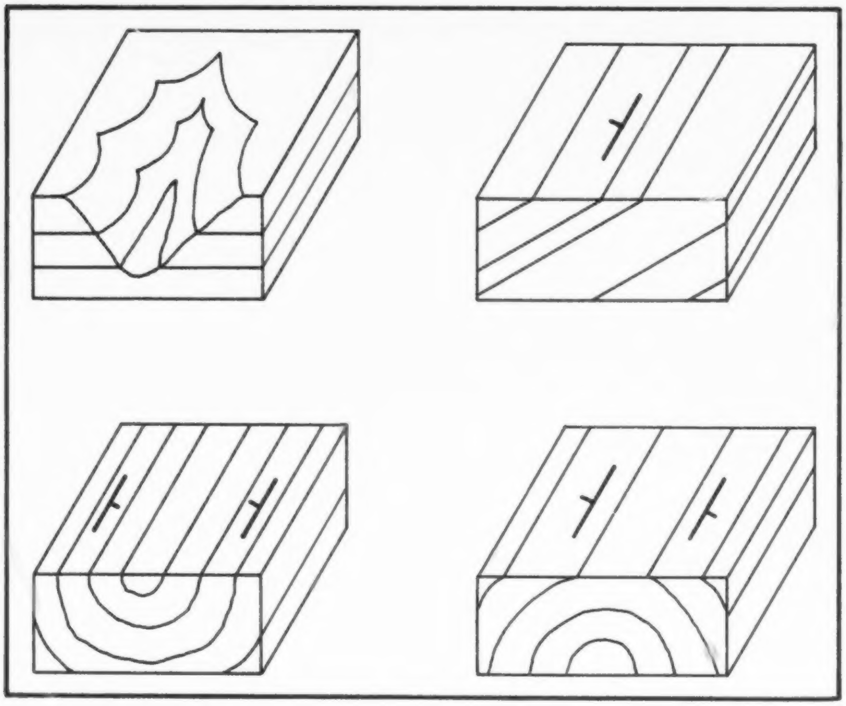


Figure 6.37. These are examples of various outcrop patterns that may be found after erosion has altered them. Note how the strike and dip symbols help show how the beds lie below the surface.

2. Drawing cross-sections: These can be drawn by simply projecting dip information, rock types, and rock thicknesses from the geologic map onto a vertical/horizontal grid. (See Figure 6.38) Cross-sections are, essentially, walls of imaginary trenches. Much insight can be gained into the geologic history of an area by studying the cross-section.

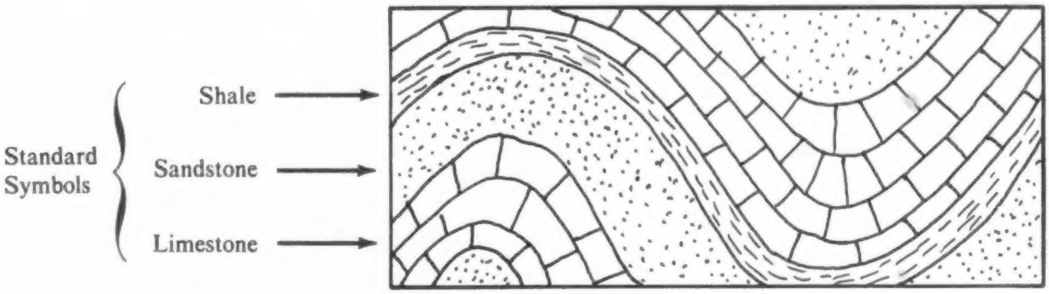


Figure 6.38. A vertical cross-section drawn from strike and dip information and rock types and thicknesses found on a geologic map.

C. Uses of geologic maps: Geologic maps are used in road and building construction, groundwater studies, dam and reservoir placement, resources exploration (minerals, oil, and gas), and any study where subsurface information is needed. They also aid in classifying soils for agricultural purposes.

SEE ACTIVITY 6.23

VIII. Summary: The study of geology requires the use of many maps, particularly since so much geologic work involves studying areas throughout the world, and the cost and time needed to visit these sites are unrealistic. Maps show the shape of the earth's surface and the underlying rock, allowing a better overall picture of the geologic nature of the earth.

Chapter 6: Problems and Questions

1. Compare and contrast topographic maps and geologic maps.
2. Explain how a point location differs from an area location.
3. Describe how the following people might use a topographic map.
   a. Home builder
   b. Hunter
   c. City planner
   d. Geology student
4. Explain the three (3) different types of map scales.
5. Explain why contour lines of different elevations cannot cross one another.
6. What is the purpose of a map profile?
7. Explain why it is necessary to have standard colors and symbols on USGS topographic maps.
8. Describe the problems encountered in trying to draw a map of the earth's surface.
9. What is the purpose of latitude and longitude? Compare and contrast the two.

Unit III: Observing the Earth

CHAPTER 7: Aerial Photographs

I. Introduction

II. Making Aerial Photographs
  A. Taking the Photographs
  B. Stereo Photographs

III. Interpreting Air Photos
  A. Cultural Features
  B. Natural Features

IV. Uses of Aerial Photographs in Geology
  A. Locating Mineral Resources
  B. Updating Maps
  C. Identifying Rock Structure
  D. Appraising Possible Geologic Hazards
  E. Monitoring Water Resources

V. Summary

Related Activities

Vocabulary

Identify information provided by stereo photographs.

Problems and questions

Aerial Photograph Geo Facts

Walter Bentley Woodbury, an Englishman, obtained a patent in England for "balloon photography" in 1877.

American forces in Cuba during the Spanish-American War tried to take photographs from balloons using a camera suspended from cables underneath the basket of the balloon.

In 1909, the first air photo was taken from an airplane piloted by Wilbur Wright.

The first nighttime aerial photograph was taken over Rochester, New York, in 1925. During a bright flash of light, Lt. George W. Goddard photographed the city from an army Martin bomber.

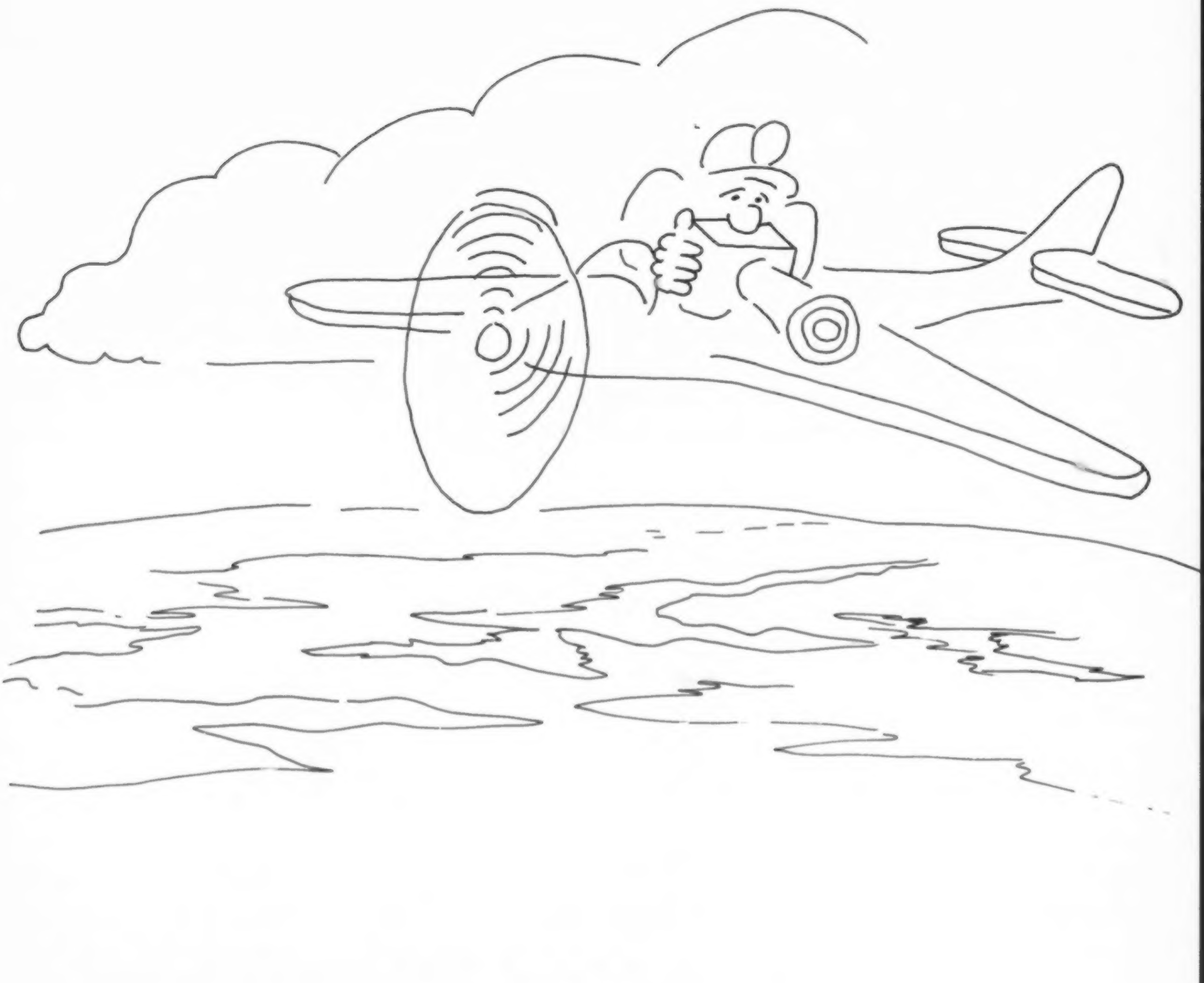
Reconnaissance aerial photography was highly publicized when Gary Powers and his U-2 were shot down and captured in Soviet territory in 1958.

Your house is difficult to recognize on an aerial photograph.

Chapter 7: Word List

Just Plane Terms

- Aerial photograph
- Stereo photograph
- Stereoscope
- Stereovision



UNIT III: OBSERVING THE EARTH

Chapter 7: Aerial Photographs

I. Introduction: Today, many maps of the earth's surface are constructed using data interpreted from aerial photographs. Aerial photographs are a series of photographs taken from the air. Their purpose is to aid in the recognition and understanding of typical landforms and patterns. They are a rapid, relatively inexpensive method of surveying hard-to-reach land areas which might take months to survey on the ground. However, they can be photographed in a matter of days.

II. Making aerial photographs: Aerial photographs are taken from planes which are equipped with cameras designed especially for that purpose.

- A. Taking the photographs: The planes fly at predetermined speeds and altitudes. The altitudes depend upon the accuracy and amount of detail required, and they vary from 1,000 feet to as high as five miles. The plane flies back and forth on parallel courses, taking photographs at frequent intervals until the areas are covered. The photographs taken on the two adjacent courses overlap, with about 60 percent of the ground in one photograph being included in the next photograph.
- B. Stereo photographs: A single aerial photograph does not show elevations, but pairs of overlapping photographs (stereo photographs) of the same area may effectively show depth. The ability of each of your eyes to see an object from a slightly different position, thus viewing in three-dimensions, is called stereovision. Two like-images are merged together in the brain, resulting in a single picture with depth and spacing. (See Figure 7.1) Two overlapping aerial photographs give this same effect, which is particularly apparent with the use of a stereoscope (lenses through which stereo photographs are viewed).

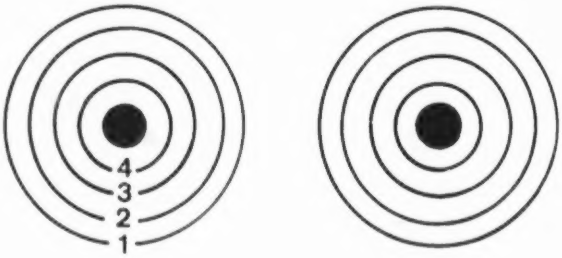


Figure 7.1. To see stereovision, focus your eyes on some point in the distance and raise Figure 7.1 up in front of you at arm's length until the two groups of circles come into your line of sight. If you continue to focus on that distant point, the two circles will seem to merge, and you will get a stereoscopic effect. Circles 1 and 2 will appear to be closer to you than circles 3 and 4.

III. Interpreting air photos: As with maps, very little use can be made of air photos unless the student can recognize and understand the features seen in the photograph.

- A. Cultural feature: For most, these are easier to recognize, since man-made structures tend to form regular patterns and shapes, such as straight lines, rectangles, and circles.
- B. Natural features: In general, the large-scale natural features that are most easily recognizable are hills, valleys, and forests. However, when dealing with specific kinds of geologic structures, or landforms, a more detailed study of the photograph will be required for identification.

IV. Uses of aerial photographs in geology: Aerial photography, due to its accuracy, detail, and accessibility, has been one of the most important advances in the study of geology in the last 20 or 30 years. Some important areas of use include the following.

A. Locating mineral resources: Aerial photography is useful in the location of mineral resources by having access to normally inaccessible areas.

B. Updating maps: Many changes occur between the time of mapping and the time of photography; thus, maps can be brought up-to-date.

C. Identifying rock structure: Sometimes, photographs covering an entire region aid in the identification of a geologic structure that is less obvious on a map.

D. Appraising possible geologic hazards: Aerial photographs aid in appraising the probability of geologic hazards such as earthquakes and landslides.

E. Monitoring water resources: Information from aerial photos can be added to data collected from measurement stations at specific locations that are monitoring water. In addition, they provide more exact locations showing the distribution of snow and ice.

SEE ACTIVITY 7.1

V. Summary: Aerial photography represents a sophistication to mapping. As technology continues to improve, so will the use and importance of aerial photos. While your eyes are crossing in an attempt to see three-dimensions on a stereo photo through a stereoscope, just remember that those photos may help locate future mineral resources for you!

Chapter 7: Problems and Questions

1. Explain why aerial photos might be more useful than maps, at certain times.
2. What general differences would you look for in determining whether a feature on an aerial photo is man-made or natural?
3. What advantages do stereo photos have over single aerial photos?
4. List two (2) uses of aerial photos in the study of geology.

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GEOLOGY IS

Preliminary Edition

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VOLUME 1 ACTIVITY SHEETS

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ACTIVITY 1.1: Earth Resources

Objective: To find and recognize the importance of earth resources in your environment.

Materials: Writing instrument, anything that you are aware of in your surroundings, and the ACTIVITY 1.1 chart.

Procedure: The society in which you live is heavily dependent upon earth resources. What are earth resources? They are anything from the earth that has value to man. Just look around you! How many of man's structures would exist without these earth resources? Some of the associations directly linked to the earth are obvious. Others only relate indirectly and are not obvious. For example, gravel is easy to see, but what about electricity? Is it associated with earth resources? In this exercise, you will observe your environment in several ways. Look around, and write down all the things you see that relate either directly or indirectly to earth resources. After completing the chart, observe its contents. Describe your conclusion.

Location	Product	Earth Resources Involved	Original Source
classroom			
campus			

Conclusions about earth resources and your environment:

ACTIVITY 1.2: Role of the Geologist

Objective: To summarize the magazine article "Role of Geologists in Wise Use of Earth."

Materials: Article "Role of Geologists in Wise Use of Earth," writing instrument, and ACTIVITY 1.2 form.

Procedure: One of the first problems you may encounter in any course is reading the text material, not because it is difficult reading but because you do not stop to realize what you have read. An easy method to overcome this is to stop a moment after reading each paragraph and try to summarize the general idea of the paragraph in a few words. For practice, carefully read "Role of Geologists in Wise Use of Earth." Then, in the blanks numbered for each consecutive paragraph in the article, write in a few words what you feel is the main idea of each paragraph.

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________
12. ____________________
13. ____________________

Below, in two or three sentences, give the general idea of the whole article.

____

____

____

Source: Journal of Geological Education, XXII, (Nov., 1974), pp. 221-222.

Role of Geologists in Wise Use of Earth

Mason L. Hill
Whittier, California

The science of geology is becoming more important to mankind as demands increase for more natural resources and less environmental hazards. Therefore, more people should have a better understanding of this subject and its applications and limitations in solving important human problems. And more geologists must be trained to further study and apply this science for the benefit of man.

Geologists are becoming more and more indispensable as six principal problems of mankind become more and more pressing. These problems can be expressed as follows: 1) population is increasing whereas mineral resources are becoming depleted, 2) conflict is increasing between the "haves" and the "have-nots", 3) conflict is increasing between man and other forms of life, 4) competition for the use of land and water areas is intensifying, 5) pollution of air, water and land is, in places becoming intolerable, and 6) natural catastrophes are taking an increasing toll of life and property.

Apollo missions have dramatically confirmed the isolation of life on our "blue planet". The Moon's anhydrous and chemically unaltered igneous rocks prove that it has no concentrations of mineral deposits or fossil fuels for our exploitation.

The Earth's population of 3.8 billion, perhaps going to 12 billion by the year 2020, places excessive pressure on the finite supply of material resources. The essential minerals of the Earth are nonrenewable because, for example, it takes thousands to millions of years to make petroleum or copper ore, whereas people, like weeds, can replenish and multiply themselves from seeds. Furthermore, fossil fuels are not even recyclable, and substitutes for most purposes are unknown or quantitatively insignificant. Geologists are the ones who know and are learning about the habitats of minerals resources, therefore more geologists are required in an effort to find these resources for both the short-term and long-term benefits of mankind.

The affluent people of the world continue to strive for more and more "goodies", while poor people are striving even harder to get their share. This conflict means that as the population expands both the "haves" and the "have-nots" of this world, except for a few people under special circumstances, will have to get along on less and less of the material wealth of the world. However, the rate of the inevitable deterioration in living standards can be retarded by successful exploration geologists.

Much is known about endangered species and ecologic balance, but who knows the relative importance of man or natural selection in causing faunal and floral extinctions? It has been estimated that 98% of all species known to have existed during the history of the Earth have become extinct. Geologists, paleontologists and biologists can contribute to providing the proper balance between man and his activities with other forms of life on this planet.

With competition for the use of land intensifying, including increased pressures to use less desirable and inappropriate terrains, choices need to be made for single or multiple purposes versus preservation of the natural state. Geologists are the ones who know and are learning about the stability of ground under various geologic conditions and can give important advice on the best use of specific lands for specific purposes.

Pollution of air, water and land increases as the wastes resulting from the activities of people, especially the affluent, increase on this finite globe. Some of the pollutants, such as mercury and lead in organic tissues, are cumulative and nonreversible. Geologists can contribute their share of good science and technology to minimize the sources of pollution.

Disasters such as those resulting from earthquakes, volcanic eruptions and landslides become greater as more and more people congregate in areas which are especially vulnerable to geologic hazards. Geologists are the ones who know and are learning to cope with such natural catastrophes. (In the case of earthquakes, geologists can attempt to locate potential and significant earthquake-generating faults for the possible protection of life and property. Too often, however, their partly subjective and qualitative conclusions are translated into unjustified legislation and quantitative engineering.)

All in all, with the population increasing and nonrenewable resources decreasing, the long-term future of mankind appears dismal. The economic and environmental costs of required materials, perhaps especially the fossil fuels, will gradually become too great; man will be rationed and probably forced to exist under one-world dictatorship; and, if he lasts that long, he may evolve into a one-race, barely surviving, with dwindling population preceding eventual species extinction.

However, this pessimistic long-term view of the future should be accepted as a challenge by optimistic people, especially geologists, to help postpone what seems inevitable as long as possible. They must try to balance: 1) supplies of minerals with the needs of people, 2) living conditions between the "haves" and "have-nots", 3) man's ecology with that of other life forms, 4) uses of land with conservation of nature, 5) essential activities of man with tolerable environmental pollution, and 6) geologic hazards with the protection of life and property.

In short, geologists are indispensable in attacking the principal problems of mankind on our isolated "blue planet", because they are the ones who, by training and experience, can provide some of the best advice on the wise use of the Earth for present and future generations.

There is a challenge to educational institutions to provide more and better geologists. It is even *more* important to educate the general public about the subject and its applications so that the democratic process will be more effective in solving these critical problems. This probably requires some revised educational approaches in order to expose more elementary and high school students to geology. Surely these exposures will kindle the interest of many in the fascinating problems and important applications of this subject. Thus, the desire to study geology at the university level could be increased in order to provide a more knowledgeable electorate.

ACTIVITY 1.3: "God Fought the Devil"

Objective: To summarize the magazine article "God Fought the Devil."

Materials: Magazine article "God Fought the Devil," and writing instrument.

Procedure: Read the magazine article entitled "God Fought the Devil." Below, in three or four sentences, summarize the main idea of the article.

Summary of article:

Source: Newsweek,
LXXXVIII, (Aug. 30,
1976), pp. 56,57.

'God Fought the Devil'

At the first thundering shock, Filipino soldiers stationed along the coast of Mindanao raced out of their barracks firing their rifles into the air. They thought they had been attacked by Muslim guerrillas, but they soon realized that they were caught in a massive earthquake. The tremor tore apart a dozen towns, and then sent three 18-foot walls of muddy, red water surging across the Moro Gulf. When the tidal waves receded, stranded sharks squirmed in the treetops and whole hamlets of bamboo fishing huts were gone without a trace. More than 5,000 Filipinos died and 90,000 others lost their homes in the country's worst recorded natural disaster. "God came down and fought with the devil," said one bewildered survivor. "It can be the only reason for so much destruction."

Around the world last week, natural disasters struck with an almost supernatural frequency. Earthquakes rocked central China's Szechwan Province and the Molucca Islands in Indonesia. Smaller tremors rattled Turkey, Japan and Chile. And on the French island of Guadeloupe in the Caribbean, a 4,868-foot volcano called Soufrière threatened to explode with the force of several atomic bombs. Nearly 72,000 people fled the banana and sugarcane plantations at its base after scientists warned that an incandescent gas cloud could sweep down and incinerate the area's inhabitants in an instant.

A 30-Megaton Bomb: The fears about Soufrière were as much historical as scientific. Mount Pelée on nearby Martinique erupted in 1902, claiming nearly 40,000 lives. "We live with the memory of Pelée," said one of the scientists on Guadeloupe. Soufrière began rumbling in March, and last month it started belching clouds of gas and ash. Two weeks ago, a series of small tremors caused Prof. Robert Brousse, head of the scientific team, to call for the evacuation. Brousse predicted that Soufrière could explode with the force of a 30-megaton bomb, and early last week when a strong quake struck 2 miles below the peak,it seemed that his prediction might be put to the test. But then the tremors faded, and when Brousse once again hiked to the summit, he found—for the moment, at least—nothing stronger than a trade wind.

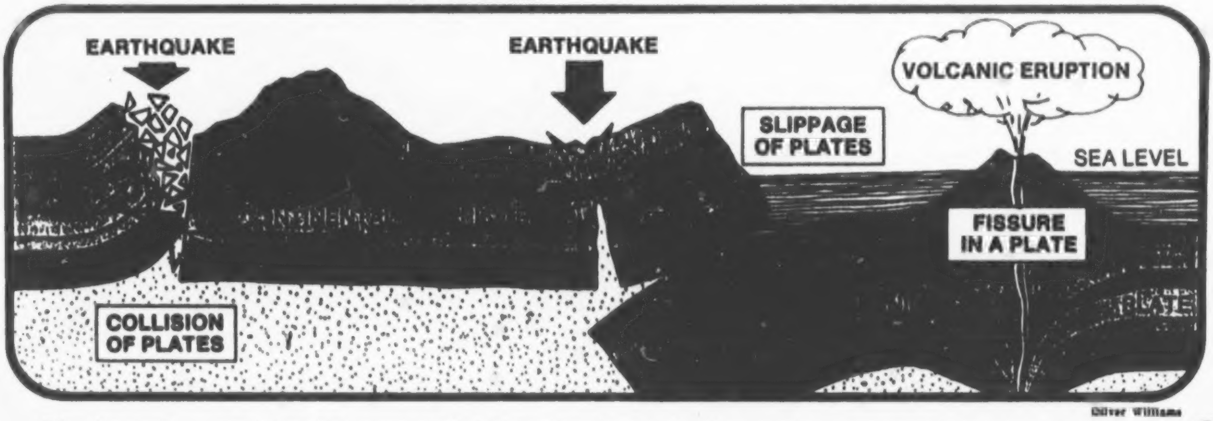
Nineteen seventy-six may yet be known as "The Year of the Upheaval." Like the powerful quakes that hit Guatemala, northeastern Italy, Russia and China earlier this year, last week's shocks probably stemmed from the movement among a dozen or so vast plates of rock on which the world's land masses rest. According to the theory of "plate tectonics," these rocky slabs slowly grind against each other with gigantic force, causing earthquakes and tearing open vents for the upwelling lava in volcanoes (sketch). "China is part of the Eurasian plate, and it is being battered on two sides," says Robert Wesson of the U.S. Geological Survey. From the south, the Indian plate is pushing against the Himalayas, while from the east the Pacific plate is wedging itself under mainland China at the rate of 4 inches a year.

Earthquakes occur at a fairly steady pace, scientists say—about 50,000 a year, most of them minor. But this year the "great" quakes (8 or above on the Richter scale) have been three times more numerous than usual, leading scientists to conclude that a three-year slowdown of major disturbances may have been reversed. And because some of the giant quakes have hit populated areas, they have been more lethal than usual.

Devastation: The Philippine quake measured 8 on the Richter scale (as againast 8.2 for the recent Chinese temblor, the worst recorded anywhere in the world for the past dozen years). It destroyed 80 per cent of Cotabato, the city of 70,000 that was near the epicenter, and badly damaged many other towns. The devastation was multiplied because the quake occurred beneath the sea floor in the mouth of the crescent-shaped Moro Gulf. The resulting tidal waves swamped 500 miles of shoreline. Thousands of villagers were swept out to sea.

Because the Moro coast is the center of the Philippines' war against secessionist Muslim guerrillas, the government was anxious to demonstrate its concern. President Ferdinand Marcos ordered round-the-clock rescue operations by the army and air force and flew to Mindanao with his Cabinet. "Most of those suffering are Muslims, and only a few Christians have been affected," he told relief coordinators. "The Christians must show the concern and sympathy that will enable them to live in cooperation with their Muslim brothers." Marcos also appealed to Filipino nationalism by spurning President Ford's offer of helicopters from the amphibious assault ship U.S.S. Tripoli and a flight of C-130s to aid the relief effort. Filipinos should "not look as if we are beggars," Marcos declared. Following China's lesson in self-reliance, the Philippines planned to depend primarily on its own efforts to heal its devastating wounds.

—KIM WILLENSON with PAUL BRINKLEY-ROGERS in the Philippines, ANDREW JAFFE on Guadeloupe and CHARLES PANATI in New York



Oliver Williams

Why the earth moves: Giant land masses grind and slip against each other, tearing open vents for the lava in volcanoes

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ACTIVITY 1.4: Scientific Method

Objective: To recognize situations using the scientific method.

Materials: Ye ol' thinking cap, writing instrument, and information below.

Part 1

Procedure: Below are several situations that begin with a problem. They are solved in various ways. You are to decide whether or not they were solved by the scientific method.

1. The Case of the Unidentified Rock: Bob and Jane find a gold-colored rock in an old rock pile behind the school. Wondering if it is real gold, they hurry to the geology lab. Various identification tests are run on the gold rock. These tests confirm that the rock is gold.

2. A family is leaving on vacation. After everyone is loaded in the car, the question is asked, "Are the doors to the house locked?" All agree that the doors are closed; all agree that if the doors are closed, they must be locked.

3. A strange looking morsel of food is placed before you by a home economics student. You are to determine if it is pleasant tasting. The appearance of the food keeps you from tasting it. Your answer is that the food is not good.

4. You are having an argument with a friend about how far it is from the geology classroom to the cafeteria. To prove you are right, you measure the distance with a tape measure, and you win the argument.

5. a. A home owner wonders about the wisdom of insulating his house. During one year, he keeps a record of all utility expenses. The next year, more insulation is added to his attic, and storm windows are installed. During the next year, a record of utility bills is kept. At the end of the second year, the expenses of the two years are compared. The expenses during the second year are considerably less than the previous year. The homeowner concludes that insulation reduces the cost of utilities.

(#5 Continues) (over)

ACTIVITY 1.4: Scientific Method (continued)

5. b. If you put much thought into the previous situation, you concluded that the scientific method was not completely followed. List all of the additional records and information needed to turn the situation into a scientific procedure.

Part 2

Procedure: Hopefully, you have seen from the examples in Part 1 that a person does not have to be a scientist to use the scientific method. In your everyday problem solving, you probably do not go beyond the hypothesis or theory stages. The important objective is that you not assume anything. In the space below, give two (2) examples of situations in which you used the scientific method to solve any problem you may have had.

1.

2.

ACTIVITY 1.5: Law of Original Horizontality

Objective: To use the scientific method and to prove the law of original horizontality.

Materials: A jar with a lid, water, sand, and writing instrument.

Procedure: You have discussed the scientific method and what is necessary for a hypothesis, then theory, and finally scientific law or principle. In this activity, you are to try to find a way to prove a general law--the law of original horizontality. The law states that essentially most sedimentary rocks are created by particles which, under the influential forces of gravity, subside to the bottom-most reaches of standing bodies of water. These sedimentary particles create horizontal layers approximately parallel to the earth's surface. You will be given materials, and from these, you are to provide proof that the above law works. Please organize your lab work as to:

1) purpose of experiment
2) material(s)
3) procedure(s)
4) result(s)
5) conclusion(s)

After the conclusion(s), state the law in your own words.

Chapter 2

ACTIVITY 2.1: Changes in Matter

Objective: To identify physical and chemical changes.

Materials: Ye ol' rusty brain (Is the rust a physical or chemical change?), and writing instrument.

Procedure: At times, changes occur to natural substances converting one form to another. These changes are classified as physical or chemical changes. Physical changes are those that occur without a change in the composition of the substance. Chemical changes result when a change in the composition of the substance occurs. Determine which of the following are physical or chemical changes. Identify by P or C on the blank line.

_______Boiling of water
_______Reaction of chlorine with sodium
_______Melting iron
_______Freezing water
_______Rusting of iron
_______Burning of wood
_______Cutting iron
_______Drinking water
_______Pumping oil
_______Burning toast
_______Souring of milk
_______Distilling oil
_______Rising of bread dough
_______Smashing your car
_______Melting of ice cream
_______Window glass being broken
_______Digestion of food
_______Gasoline exploding
_______Bending a wire
_______An earthquake
_______Crushing salt
_______Sharpening a pencil
_______Lighting a match
_______Developing film
_______Moldy cheese
_______Formation of frost
_______Sanding wood
_______Charging a battery
_______Exploding dynamite
_______A volcano erupting
_______Shattering a light bulb
_______Fizzing of Alka Seltzer

ACTIVITY 2.2: Elements, Compounds, and Mixtures

Objective: To identify different types of matter.

Materials: Thinking power and writing instrument.

Procedure: Most of the substances you will study in class or see around you can be classified as either compounds or mixtures, rather than single elements. A compound is a substance that is composed of two or more elements and can only be separated by a chemical change. For example, if you heat sugar, it will break down to carbon and water. What kind of a change is this? A mixture is two or more substances of varying composition which retain their individual identity and can be physically separated. How?____________________

____

It might also be noted that a solution is a type of mixture involving two liquids or a liquid and a solid, such as salt in water. Can you separate them physically? How?____

____

Classify the following as compound, mixture, or element by the letters C, M, or E.

_______Ham and cheese
_______Water
_______Carbon
_______Milkshake
_______Dry ice (carbon dioxide)
_______Plastic
_______Salted peanuts
_______Calcium
_______Cream of tartar $C_4H_5KO_6$
_______Air (with compounds)
_______Soil
_______Tin
_______Chocolate chip cookies

_______Buttered popcorn
_______Oxygen
_______Gold
_______Salt
_______Coal
_______Sugar
_______Coffee with cream
_______Aluminum
_______Human body (with compounds)
_______Nickel
_______Concrete
_______Uranium
_______Fruit cocktail

ACTIVITY 2.3: Periodic Table

Objective: To identify information obtained from the periodic table.

Materials: Periodic table and writing instrument.

Part 1

Procedure: Answer the following questions by referring to the periodic table.

1. Name the five (5) family members included with beryllium. What do they have in common?

2. Are potassium, iron, and zinc in the same family or the same period? What do they have in common?

3. Are lithium, magnesium, scandium, zirconium, and tantalum in the same family or period? What do they have in common?

4. Which element of the following is not a member of this family? oxygen, polonium, sulfur, antimony, tellurium, selenium

(over)

ACTIVITY 2.3: Periodic Table (continued)

Part 2

Procedure: It is possible by using information about each element supplied by a periodic table to determine the number of electrons, neutrons, and protons of a given atom. To review, here are a few simple rules:

1. Number of protons is the same as the atomic number.
2. Number of electrons equals the number of protons.
3. Atomic mass is the number of protons plus the number of neutrons.

Given the information above, fill in the blanks below.

Element	Atomic Number	Protons	Neutrons	Electrons	Atomic Mass
				8	16
Iron		26			56
Uranium			146	92	
Silicon			14		28
	20				40
					4
	11				
Hydrogen					1
		7			
Potassium					
Copper					64
	82				
				30	

ACTIVITY 2.4: Balancing Chemical Equations

Objective: To balance chemical equations.

Materials: Writing instrument.

Procedure: Balance the equations below.

1. $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

2. $Na + Cl_2 \rightarrow NaCl$

3. $NaCl + H_2SO_4 \rightarrow Na_2SO_4 + HCl$

4. $Zn + Cl_2 \rightarrow ZnCl_2$

5. $PbS + O_2 \rightarrow PbSO_4$

6. $MnO_2 + HCl \rightarrow MnCl_2 + Cl_2 + H_2O$

EXTRA CREDIT:

$NH_3 + O_2 \rightarrow NO + H_2O$

$Cl_2 + NaOH \rightarrow NaCl + NaClO_3 + H_2O$

ACTIVITY 3.1: Classifying Hard Stuff

Objective: To develop a classification system for earth materials.

Materials: Fifteen earth materials and writing instrument.

Procedure: One of the first stages of scientific research involves grouping samples according to likenesses and differences, commonly called classification. Name three (3) reasons a scientist would classify things.

____

____

____

In this exercise, you are to develop your own classification system. You will be given 15 samples of earth materials. Determine the likenesses and differences. Put them in groups of similar features. Describe each. Do this in such a manner that another person could identify each sample through your description. Make up names for each sample.

Be sure you include objectives, materials, procedure, and conclusion when you record this activity.

ACTIVITY 3.2: MINERAL IDENTIFICATION

Objective: To be able to distinguish various physical characteristics of minerals and to use them to identify specific minerals.
To use a mineral identification key to identify minerals.

Materials: Minerals, streak plate, steel file, scale, magnet, penny, glass container, string, fingernail, great memory, writing device, and plastic tray.

Procedure: This activity is divided into two parts. First, you will concentrate on determining specific characteristics of a group of 10 minerals. After you have listed each mineral's characteristics, you will work as a group to name each mineral. After the group activity, more minerals will be added to your tray and you will be asked to identify the rest yourselves. Remember - be sure you know what you did in part one before going on to part two.

Part 1: MINERAL PHYSICAL PROPERTIES LAB

Purpose: To use a mineral's physical and chemical properties to determine a mineral's physical characteristics.

1. Obtain a plastic lab tray with 10 minerals, a streak plate (the square, flat, white thing).

2. Place the minerals on or by the mineral chart in the order given you by your instructor.

3. Now list the following physical characteristics for each mineral on your chart.

   a) Color: List the color of each mineral.

   b) Streak: Using the streak plate, scratch each mineral on it to determine the color of streak, if any, of each mineral.

   c) Transmission of light: Determine if the mineral is transparent, translucent, or opaque.

   d) Luster: Determine whether the mineral's luster is metallic or nonmetallic.

   e) Cleavage: Observe each mineral to determine if the mineral has cleavage or fracture.

   f) Hardness: Using the minerals themselves and any reference objects for hardness, list the relative hardness of the minerals.

ACTIVITY 3.2 MINERAL IDENTIFICATION (continued)

Part 1 continued:

g) Specific gravity: Determine the specific gravity of each mineral. To do this, first get a glass jar, a piece of string, and a scale. Fill the jar 3/4 full of water. Tie the string, around the mineral, attach it to the scale, and weigh it. Next, submerge the attached mineral into the water, and weigh it. Subtract to obtain the difference. Finally, divide the dry weight of the mineral by the weight loss to determine the specific gravity. Enter the answer on the chart.

4. After your chart is complete, answer the following questions.

    a) What is the difference in cleavage and fracture?

    b) What is meant by the fact that Moh's scale is relative?

    c) What does the specific gravity number mean?

    d) How can knowing these characteristics help you identify a specific mineral?

    e) Why will it take three or four physical properties before you can identify a specific mineral?

At this point, you are ready to use the Mineral Identification Charts and actually identify the ten minerals.

The following is an outline of the Mineral Identification Chart. Look at it carefully, it will help you use the chart.

Outline of Mineral Identification Charts

LUSTER: METALLIC OR SUBMETALLIC

1. Soft: Will mark on paper.
2. Medium hardness: Can be scratched with knife but will not readily leave mark on paper.
3. Hard: Cannot be scratched with knife.

LUSTER: NONMETALLIC
1. Streak definitely colored.
2. Streak colorless: Can be scratched with fingernail.
3. Streak colorless: Cannot be scratched with fingernail; can be scratched with copper penny.
    a. Cleavage well-developed.
    b. Cleavage poor or absent.
4. Streak colorless: Cannot be scratched with penny; can be scratched with knife.
    a. Cleavage well-developed.
    b. Cleavage poor or absent.

ACTIVITY 3.2 MINERAL IDENTIFICATION (continued)

Part 1 continued:

LUSTER: NONMETALLIC (continued)

5. Streak colorless: Cannot be scratched with knife; can be scratched by quartz.
    a. Cleavage well-developed.
    b. Cleavage poor or absent.

Use of the chart is simply a process of elimination. Eliminate those characteristics that don't match until you have the right mineral! And what will be left should match.

Here are some suggestions for using the chart.

Part 2: Use of the Mineral Identification Charts:

1. Properties must be determined for individual mineral grains. In a collection of grains (aggregate), single grains must be tested, not the aggregate as a whole.

2. Observe the luster of your mineral. Choose the chart which specifies the luster you have described.

3. Within a single luster chart (e.g., metallic), choose the chart which includes minerals with the correct range of hardness.

4. For nonmetallic minerals, ranges of cleavage are also placed in separate sections of the chart.

5. Use the rest of the physical properties to narrow down the possible choices until only a single possible name remains.

6. Note that a given mineral may appear on more than one of the charts. Some minerals occur in various forms in which properties vary enough that it is necessary to include them on several charts.

7. After you have identified the mineral on the Mineral Identification Chart, write down the name of the mineral on the blank chart provided with the activity.

Now that you have identified your first ten minerals (you mean there are more?!), fill out the information on your mineral identification chart. After you have done that for all ten, you can now procede on with the new minerals your teacher has added. Again, use the same techniques of elimination and classification. NOTE: You do not have to write down all of the characteristics of each new mineral unless you want to, but you do have to fill out information on the chart for each one.

ACTIVITY 3.2: Mineral Identification (continued)

Below are a few questions to give you a practice run with the mineral charts:

Mystery mineral has a metallic luster.

Mystery mineral has a hardness of 6. What are the possible minerals having this hardness?

Mystery mineral has a black streak.

Mystery mineral is black. Now what possibilities are there?

Mystery mineral has a rather heavy specific gravity. To what does this characteristic narrow down the possibilities?

The mystery mineral is ____________________________.

Next, mysterious mineral has a nonmetallic luster. Mysterious mineral is white. What are the possibilities?

Mysterious mineral has a colorless streak.

M.M. has three perfect cleavages that are not at right angles. Now what do you know?

Mysterious mineral has a hardness of 3. What possible minerals are left?

MINERAL PHYSICAL PROPERTIES LAB

	Color	Streak	Light	Luster	C/F	Hardness	Specific Gravity
1							
2							
3							
4							
5							
6							

	Color	Streak	Light	Luster	C/F	Hardness	Specific Gravity
7							
8							
9							
10							

LUSTER: METALLIC OR SUBMETALLIC

1. Soft: Will mark on paper (<2½).

Streak	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
gray to black	steel-gray to black	1-1½	2.3	one perfect cleavage, feels greasy, greasy luster	GRAPHITE C hexagonal	pencil "lead," lubricants
red-brown	brick red to brownish	1+	5.2	earthy looking, massive, sometimes kidney-shaped	HEMATITE, Common Red or Massive Fe_2O_3 hexagonal (trigonal)	iron ore

2. Medium Hardness: Can be scratched with knife but will not readily leave mark on paper (>2½<5½).

gray-black	blue-black to gray	2½	7.6	3 perfect cleavages at right angles	GALENA PbS cubic	lead ore
bright copper	copper to brown	2½-3	8.9	fractures rather than cleaves, malleable, soft	COPPER Cu cubic	minor copper ore
black	brass-yellow	3½-4	4.2	usually massive; associated with pyrite	CHALCOPYRITE $CuFeS_2$ tetragonal	important ore of copper
light yellow to dark brown	light to dark brown (yellowish)	3½-4	4.0	6 perfect cleavage directions, resinous luster	SPHALERITE ZnS cubic	zinc ore
red-brown	dark brown, steel gray, black	5½-6½	4.8-5.3	usually harder than knife, sometimes in flakes	HEMATITE, Specular Fe_2O_3 hexagonal (trigonal)	iron ore
yellow-brown	dark brown to black	5-5½	3.6-4.0	dull or earthy luster, rust stains common	LIMONITE $Fe_2O_3 \cdot H_2O$ amorphous	iron ore (bog ore)

The descriptions given in these mineral charts are generalized. There can be exceptions to these descriptions.

3. Hard: Cannot be scratched with knife (>5½).

Streak	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
black	pale brass-yellow	6-6½	5.0	striated cubes, massive, granular, no cleavage	PYRITE FeS_2 cubic	used in manufacture of sulfuric acid
black	black	6	5.2	magnetic, cubic crystals	MAGNETITE Fe_3O_4 cubic	iron ore

LUSTER: NONMETALLIC

1. Streak definitely colored.

Streak	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
blue	azure-blue to dark-blue	3½-4	3.7	brittle, effervesces in dilute HCl	AZURITE $Cu_3(CO_3)_2(OH)_2$ monoclinic	minor ore of copper, decoration
light green	bright green	3½-4	4.0	reacts with HCl, uneven fracture, silky to dull luster	MALACHITE $Cu_2(CO_3)(OH)_2$ monoclinic	copper ore
white	white or pale colors	2-2½	2.8-3.0	foliated "books," hexagonal-shaped plates, elastic, glassy luster	MUSCOVITE (MICA) $KAl_3Si_3O_{10}(OH)_2$ monoclinic sheets	high temperature electrical insulation, rock former
white to gray	dark-brown	2½-3	3.0	foliated "books," hexagonal-shaped plates, elastic, glassy luster	BIOTITE (MICA) $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$ monoclinic sheets	insulation rock former
white	green to white	1+	2.7-2.8	greasy feel, impure varieties may appear harder than 1, pearly luster	TALC $Mg_3Si_4O_{10}(OH)_2$ monoclinic sheets	ceramics, talcum powder, fillers, sinks, table tops
white	white	2-2½	2.6	claylike, earthy odor, sticks to tongue, powdery aggregates	KAOLINITE $Al_4Si_4O_{10}(OH)_8$ triclinic sheets	ceramic and paper industries

2. Streak colorless: Can be scratched with fingernail ($<2\frac{1}{2}$).

Cleavage	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
1 perfect, 2 good	white, colorless	2	2.3	glassy to pearly luster, massive varieties are granular or fibrous	GYPSUM, Selenite $CaSO_4 \cdot 2H_2O$ monoclinic	Plaster of Paris, plaster board, Portland cement
none	yellow to yellowish brown	$1\frac{1}{2}$-$2\frac{1}{2}$	2.07	brittle, resinous to greasy luster, conchoidal to uneven fracture	SULFUR S orthorhombic	used in manufacture of sulfuric acid, fertilizers, and drugs

3. Streak colorless: Cannot be scratched with fingernail; can be scratched by copper penny ($>2\frac{1}{2}<3$).

a. Cleavage well-developed.

Cleavage	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
3 perfect, at right angles	colorless to white	$2\frac{1}{2}$	2.2	soluble in water, tastes salty, granular masses or large single crystals	HALITE NaCl cubic	rock salt **rock former**
3 perfect, not 90° angles	colorless, white, or colored	3	2.7	effervesces in cold acid, glassy luster, often in granular masses	CALCITE $CaCO_3$ hexagonal (trigonal)	Portland cement, fertilizers **rock former**

b. Cleavage poor or absent.

none	yellow, brown, gray	1-3	2.0-2.5	earthy masses that often contain pea-sized circles, claylike odor	BAUXITE $Al_2O_3 \cdot nH_2O$ orthorhombic	aluminum ore

4. Streak colorless: Cannot be scratched with penny; can be scratched with knife (>3<5½).

a. Cleavage well-developed.

Cleavage	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
4 perfect	colorless, white, violet, green, yellow	4	3.2	cubic crystals, transparent to translucent, glassy luster	FLUORITE CaF_2 cubic	hydrofluoric acid, production of aluminum and steel
3, one at right angles to other two	colorless, white	3-3½	4.5	characterized by high specific gravity, often has red-yellow stains	BARITE $BaSO_4$ orthorhombic	drilling mud, cosmetics, and medicine

b. Cleavage poor or absent.

1 poor (basal)	colorless, green, blue, brown	5	3.2	good six-sided crystals common, glassy to greasy luster	APATITE $Ca_5(F,Cl,OH)(PO_4)_3$ hexagonal	fertilizers, source of phosphorous, gem stones

5. Streak colorless: Cannot be scratched with a knife; can be scratched with quartz ($>5\frac{1}{2}<7$).

a. Cleavage well-developed.

Cleavage	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
2 directions at 60° & 120°	dark green, brown, black	6	3.0-3.4	long prismatic six-sided crystals, glassy to dull luster	AMPHIBOLE group (HORNBLENDE) $NaCa_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$ monoclinic	rock former, used to confuse students with augite
2 good, at nearly 90°	colorless, pink, green, white, gray	6	2.5	pearly to glassy luster	K-FELDSPAR (ORTHOCLASE) $KAlSi_3O_8$ (MICROCLINE) monoclinic or triclinic	ceramics, glass, scouring powder, rock former
2 good, at nearly 90°	colorless, white, gray	6	2.6-2.7	on one of the cleavages may be found fine lines or striations	Na,Ca-FELDSPAR (PLAGIOCLASE) $NaAlSi_3O_8$, $CaAl_2Si_2O_8$ triclinic	ceramics and glass, ornamental purposes rock former
2 good, at nearly 90°	black to dark green	5-6	3.1-3.5	stubby rectangular crystals, some varieties light-colored	PYROXENE group (AUGITE) $Ca(Mg,Fe,Al)(Al,Si)_2O_6$ monoclinic	gem stones, rock former

5. Streak colorless: Cannot be scratched with a knife; can be scratched with quartz ($>5\frac{1}{2}<7$). (continued)

b. Cleavage poor or absent.

Cleavage	Color	Hardness	S.G.	Other Properties	Name Chemical Composition Crystal System	Importance
none	colorless, white, smoky, violet, rose	7	2.6	crystals horizontally striated, conchoidal fracture, glassy luster	QUARTZ SiO_2 hexagonal (trigonal)	gems, electronic devices, glass, abrasive, rock former
none	various dark colors, may be banded	6-6.5	2.6	waxy to dull luster, conchoidal fracture with sharp edges	FLINT (form of quartz) SiO_2	primitive tools, arrowheads
none	olive green to yellowish green	6.5-7	3.5-4.5	sugary in appearance, conchoidal fracture, glassy luster	OLIVINE $(Mg,Fe)_2SiO_4$ orthorhombic	rock former, used in manufacture of refractory bricks
none	gray, blue, pink, brown	9	4.0-4.1	brittle, barrel-shaped crystal, sometimes massive or granular	CORUNDUM Al_2O_3 hexagonal (trigonal)	valuable as an abrasive in the form of emery, gem stones

MINERAL CHART

NAME	CHEMICAL COMPOSITION	MINERAL GROUP*	USE OR IMPORTANCE	IMPORTANT IDENTIFYING CHARACTERISTICS

* The mineral group can be determined by comparing its' mineral composition to the grouping of minerals in the text.(part IV.)

MINERAL CHART

NAME	CHEMICAL COMPOSITION	MINERAL GROUP*	USE OR IMPORTANCE	IMPORTANT IDENTIFYING CHARACTERISTICS

* The mineral group can be determined by comparing its' mineral composition to the grouping of minerals in the text.(part IV.)

MINERAL CHART

NAME	CHEMICAL COMPOSITION	MINERAL GROUP*	USE OR IMPORTANCE	IMPORTANT IDENTIFYING CHARACTERISTICS

* The mineral group can be determined by comparing its' mineral composition to the grouping of minerals in the text.(part IV.)

Chapter 4

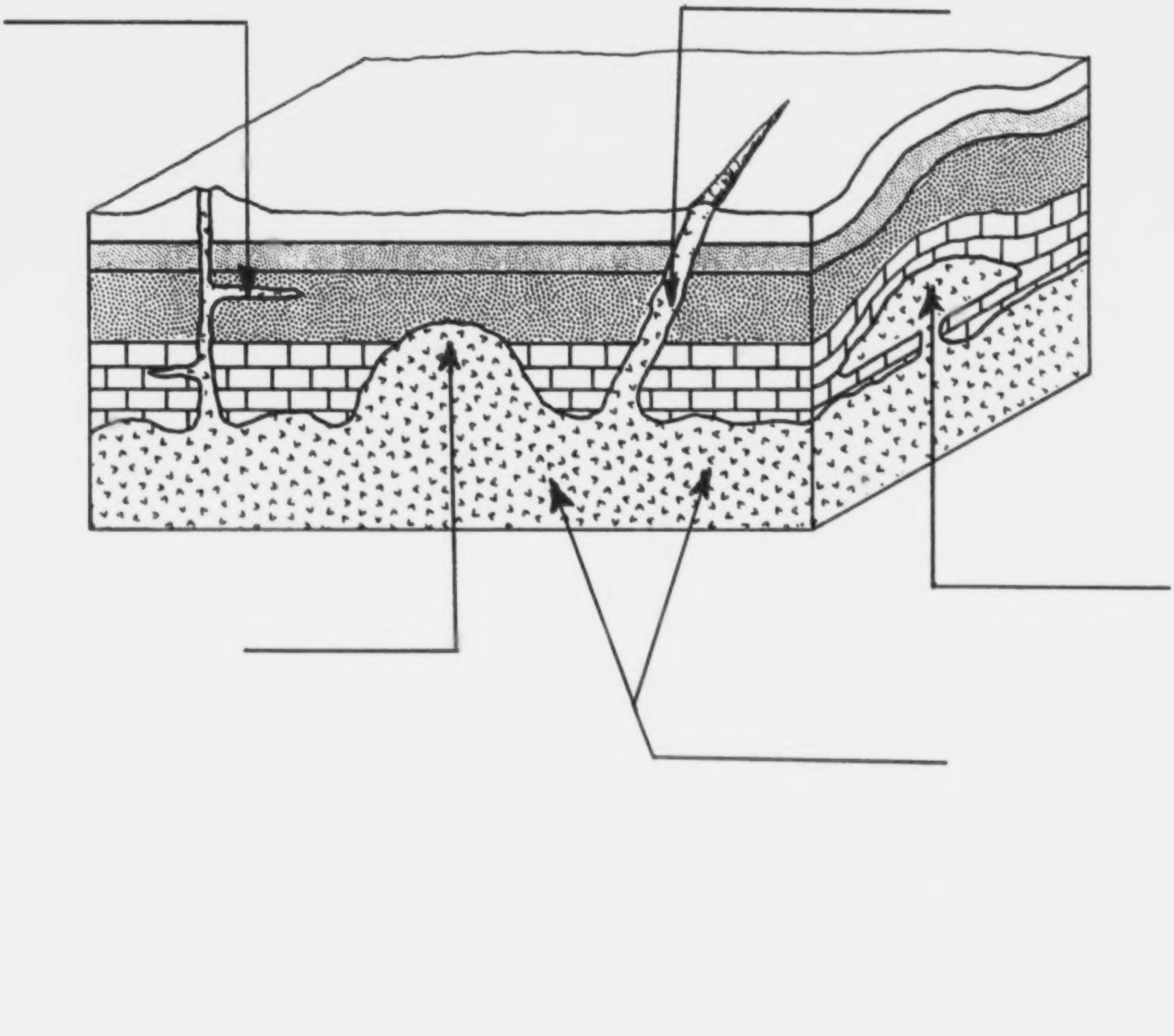
ACTIVITY 4.1: Intrusive Features

Objective: To identify various intrusive or plutonic features by their geologic name.

Materials: Writing instrument and diagram below.

Procedure: Label the following features in the diagram below. Using information in chapter, description of intrusive features:

Batholith	Sill
Dike	Stock
Laccolith	



ACTIVITY 4.2: Igneous Rocks

Objective: To identify igneous rocks.

Materials: Igneous Rock Classification Key, various mystery rocks, Igneous Rock Chart, hand lens, keen mind, and cylinder of pine with graphite and clay in the middle and an eraser-like object on the end.

Procedure: The following are instructions for using the Igneous Rock Classification Key. Follow each step to aid you in identifying igneous rocks.

1. Determine if the rock is dark (black, dark gray, or green) or light (any color other than black, dark gray, or green) in color. If it is darker, you will be using the top half of the Key. If it is lighter, the bottom half of the Key will be used.
2. Observe the texture. Is it glassy, fine-grained (aphanitic), fine-grained with large crystals (porphyritic), coarse-grained with large crystals, or coarse-grained (phaneritic)? Locate the textures at the bottom of the Key. Find the appropriate column, and follow it up to the half of the Key you chose for color. In most cases, the mineral should be identified. For example, if you receive a black, fine-grained rock, you can easily (?) conclude that it is basalt.
3. After identifying your rock, go directly across the Key to the Minerals section. The distance between the vertical lines above each mineral indicates the abundance of each mineral in your rock. Now you can list the minerals found in your rock.
4. Refer to the Igneous Rock Chart following the Classification Key. You are to fill in all of the information about your rock--Rock Family (acidic, intermediate, basic), Texture (glassy, aphanitic, porphyritic, phaneritic), Predominant Minerals, Geologic Occurrence (extrusive, intrusive), and Name.

Below are a few examples to give you a practice run:

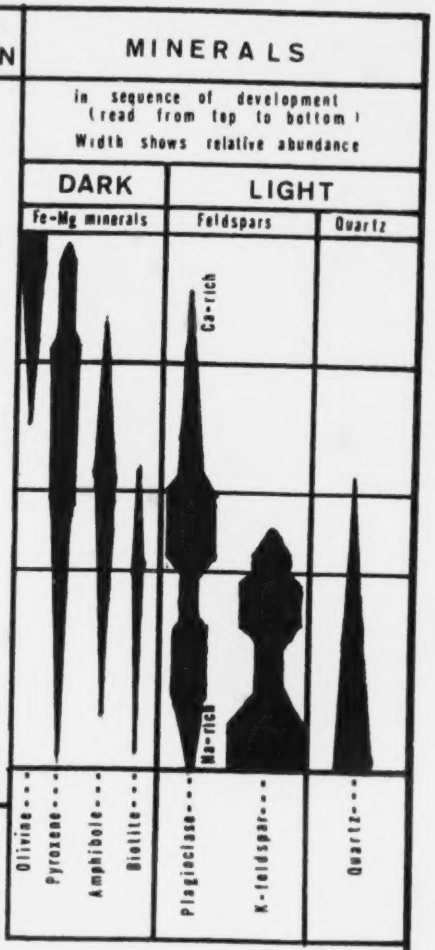
Mystery Rock is coarse-grained and is composed largely of olivine.

Somewhat Mysterious Rock is red and glassy. What is S.M.R.'s identity?

This Dead-Give-Away has approximately 30 percent dark minerals and is coarse-grained. D.G.A. is ___________________________.

IGNEOUS ROCK CLASSIFICATION KEY

GEOLOGIC OCCURRENCE						ROCK FAMILY	CRYSTAL FORMATION
Extrusive				Intrusive			
Volcanic explosion debris	Lava flows and hot siliceous clouds		Lava flows Small shallow masses	Medium masses at medium depth	Medium to large deep-seated masses		
VERY UNCOMMON					PERIDOTITE	ULTRABASIC (essentially all dark minerals)	1200°C
TUFF Lithified ash VOLCANIC BRECCIA	OBSIDIAN PUMICE SCORIA Black or red glass	BASALT	BASALT PORPHYRY	GABBRO PORPHYRY	GABBRO (if fine-grained in tabular masses) DIABASE	MAFIC BASIC (dark minerals dominant)	↓
		ANDESITE	ANDESITE PORPHYRY	DIORITE PORPHYRY	DIORITE	INTERMEDIATE (25-50% dark minerals)	900°C
		FELSITE		GRANITE PORPHYRY	GRANITOID ROCK SYENITE	FELSIC ACIDIC (<25% dark minerals)	
		RHYOLITE	RHYOLITE PORPHYRY		GRANITE		600°C
Fragmental Pyroclastic	Glassy Frothy	Aphanitic (fine)	Porphyritic (>25% large crystals)	Porphyritic (>25% very large crystals)	Phaneritic (coarse)		
TEXTURE							



IGNEOUS ROCK CHART

NAME	TEXTURE	GEOLOGICAL OCCURRENCE	PREDOMINANT MINERALS	ROCK FAMILY

IGNEOUS ROCK CHART

NAME	TEXTURE	GEOLOGICAL OCCURRENCE	PREDOMINANT MINERALS	ROCK FAMILY

ACTIVITY 4.3: Sedimentary Rocks

Objective: To identify sedimentary rocks.

Materials: Sedimentary Rock Classification Key, mystery rocks, HCl, hand lens, Sedimentary Rock Chart, and writing instrument.

Procedure: Follow the numbered instructions to aid you in using the Sedimentary Rock Classification Key and in identifying sedimentary rocks.

1. The Key is divided into two parts--clastic rocks and nonclastic rocks. If you recall, clastic rocks are those formed from fragments of material. Nonclastic rocks are from solutions resulting from various chemical or organic processes and then precipitated.
2. Look at your rock. Determine whether it is clastic or nonclastic.
3. If the rock is a clastic, use chart A. Consider the grain size. Are the grains gravel size, sand size, silt size, or clay size?
4. If the grain size does not determine the identity, consider the composition. Now you should have your rock name.
5. If the rock is nonclastic, refer to chart B. First determine its composition. Is it composed of calcite, dolomite, chalcedony, gypsum, or halite? By determining the composition, you can eliminate several possibilities.
6. Now, if your rock is still not identified, look at the texture. After determining the texture and finding it on the Key, you have your rock name--Bingo!
7. Refer to the Sedimentary Rock Chart. From the Key, you can fill in nearly all the necessary information about your rock--Texture, Clastic or Nonclastic, Composition, and Name. You can find Environment in part III C of Chapter 4.

Below are a few examples to give you practice:

This rock is a clastic rock. It is extremely fine-grained, of clay-sized particles. The rock is __________________.

(over)

ACTIVITY 4.3: Sedimentary Rocks (continued)

A nonclastic, the composition is calcite. What are the possibilities?

It has fossils that are held together by a concretish mixture. It is ________________________.

Obviously clastic, this rock is composed of gravel-sized fragments. What are your guesses?

The fragments are rounded. O.C. is ________________________.

SEDIMENTARY ROCK CLASSIFICATION KEY

A. Clastic Rocks

TEXTURE	COMPOSITION/CHARACTERISTICS	ROCK NAME
Gravel Size Range (over 2 mm)	Rounded fragments of any rock type; quartz, quartzite, chert dominant	CONGLOMERATE
	Angular fragments of any rock type; quartz, quartzite, chert dominant	BRECCIA
	Glacial deposits, various sizes, rounded	TILLITE
Sand Size Range (1/16 mm to 2 mm)	Quartz with minor accessory minerals (sand)may be any color	SANDSTONE
	Quartz with at least 25% feldspar (sand) pink to brown in color	ARKOSE
Silt Size Range (1/256-1/16 mm)	Quartz and clay minerals (mud) layered	SILTSTONE
Clay Size Range (less than 1/256 mm)	Quartz and clay minerals (fine mud) laminated (layers)	SHALE

B. Nonclastic Rocks

CHARACTERISTICS	COMPOSITION	ROCK NAME
Visible crystals of calcite, variety of colors	---------------------	CRYSTALLINE LIMESTONE
Massive, smooth shell-like fracture	---------------------	MICRITE LIMESTONE
Composed of oolites (small circular features)	---------------------	OOLITIC LIMESTONE
Loosely cemented shells (actually pieces of shells)	---Calcite ($CaCO_3$)---	COQUINA
Abundant fossils in calcareous matrix	---------------------	FOSSILIFEROUS LIMESTONE
White to gray, soft microscopic shell fossils	---------------------	CHALK
Banded layers of calcite, found near springs	---------------------	TRAVERTINE
Char. similar to limestone but reacts very slowly with HCl	Dolomite $CaMg(CO_3)_2$	DOLOSTONE (Dolomite)
Massive (Microcrystalline) variety of colors, doesn't react with HCl	Chalcedony (SiO_2)	CHERT, etc.
Crystalline, layered soft, light colored	Gypsum ($CaSO_4 + 2H_2O$)	GYPSUM
Layered white to gray, "salty"	Halite (NaCl)	ROCK SALT
Brown to black, layered, may contain organic plant remains	Vegetation--Carbon plant remains	COAL

SEDIMENTARY ROCK CHART

NAME	CLASTIC NON-CLASTIC	TEXTURE / COMPOSITION	IDENTIFYING CHARACTERISTICS	FORMATIVE ENVIRONMENT*

* Formative environments are found in the text, Chapter 4,III D. You may use the major subdivisions: Marine, Transitional, Continental and Replacement. Remember, you may have to use more than one.

SEDIMENTARY ROCK CHART

NAME	CLASTIC NON-CLASTIC	TEXTURE / COMPOSITION	IDENTIFYING CHARACTERISTICS	FORMATIVE ENVIRONMENT*

* Formative environments are found in the text, Chapter 4, III D. You may use the major subdivisions: Marine, Transitional, Continental and Replacement. Remember, you may have to use more than one.

ACTIVITY 4.4: Metamorphic Rocks

Objective: To identify metamorphic rocks.

Materials: Metamorphic Rock Classification Key, more mystery rocks, HCl, hand lens, Metamorphic Rock Chart, and writing instrument.

Procedure: Follow these instructions to guide you in your use of the Metamorphic Rock Classification Key and in the identification of metamorphic rocks.

1. The Metamorphic Rock Classification Key classifies metamorphic rocks according to texture and then according to composition.
2. Determine whether or not your rock is foliated. The foliated rocks occupy about the top half of the Key.
3. Next, decide whether the rock is very fine, fine, medium, or coarse-grained. You should now know the name of your rock.
4. If there is still a problem in identification, such as with quartzite or marble, it is necessary to consider the composition. With these two rocks, for instance, decide whether they contain quartz or calcite.
5. Refer to the Metamorphic Rock Chart. From the information provided on the Key, you can fill in the information about Texture, Parent Rock, Metamorphic Environment, and Rock Name. You can find Environment in part IV C of Chapter 4.

Below is your last practice run:

A foliated, coarse-grained, banded rock is ______________________.

A non-foliated, coarse-grained rock composed of quartz is ____________________________________.

A foliated, very fine-grained rock is _____________________________.

METAMORPHIC ROCK CLASSIFICATION KEY

			ROCK NAME	COMPOSITION	PARENT ROCK	METAMORPHIC ENVIRONMENT
TEXTURE	FOLIATED	Very fine-grained	SLATE	Abundance of dark, flaky, and/or silicate minerals (micas, chlorite, talc, serpentine, hornblende, etc.); quartz	Shale; tuff	REGIONAL INCREASING ↓
		Fine-grained	PHYLLITE		Shale; tuff	
		Medium to coarse-grained (oriented)	SCHIST (var. mica schist, chlorite schist, amphibole schist, etc.)		Shale; intermediate to basic igneous rocks	
		Medium to coarse-grained (banded)	GNEISS (var. garnet gneiss, granite gneiss, etc.)	Feldspar abundant; varying amounts of quartz and dark silicate minerals (such as amphiboles, pyroxenes, micas, and garnet)	Light to intermediate igneous rocks; arkose; graywacke, mica schist	Regional
	NONFOLIATED	Medium to coarse-grained	QUARTZITE	Quartz greatly predominant	Normal and quartzose sandstones	Regional or contact
			MARBLE	Calcite and/or dolomite with or without Ca-Mg silicates	Limestone or dolomite with or without impurities	Regional or contact
		Fine to very fine-grained	HORNFELS	Dark silicate minerals predominant	Shale; slate; intermediate to mafic extrusive rocks	Contact
			ANTHRACITE	92-98% carbon	Peat, lignite, coal	Regional or contact

METAMORPHIC ROCK CHART

NAME	TEXTURE	COMPOSITION	PARENT ROCK	IDENTIFYING CHARACTERISTICS

Chapter 4

ACTIVITY 4.5: Geologic Time

Objective: To measure geologic time by scale on paper.

Materials: One piece of paper tape slightly greater than five meters in length, freshly sharpened pencil or ball point pen, Table 2.4, and meter stick.

Procedure: Compared to the span of the earth's history, a human lifetime is very short. This makes it very difficult for any person to get a clear picture of the vast periods of time involved in geologic history. However, some feeling for these time spans is necessary for you to understand the slowness of the processes that change the earth and the life on it. The procedures you will follow in this activity will help you make your personal discovery of the real meaning of geologic time. By converting geologic time into distances, it will be possible for you to make a correctly scaled model of the earth's history. Follow the instructions below.

1. In order to translate time into equivalent distances, you must first work out a scale. To do this, let 1 meter equal 1 billion (1,000,000,000) years. Now complete the missing parts of the scale below. Remember, 1 meter = 100 centimeters
   1 centimeter = 10 millimeters.

   1 meter = 1,000,000,000 years

   1 centimeter = (a)________________ years

   1 millimeter = (b)________________ years

2. Using the scale you have developed, translate each of the ages given on Table 2.4 into its equivalent distance in meters. For example, an age of 460 million years becomes 46 cm = 46/100 mm = 0.46 m. An age of 9 million years becomes 9 mm = 9/1000 = 0.009 m.

(over)

ACTIVITY 4.5: Geologic Time (continued)

3. Obtain a piece of paper tape slightly greater than five meters in length. About one centimeter from one end of the tape, make a straight line across with a freshly sharpened pencil or a ball point pen. Label this line with the word "NOW."

4. Using a meter stick, measure along the tape the proper distance from the "NOW" line to represent the time for the earth's maximum age. Draw a fine line across the tape to mark this point, and label it "Maximum Age of Earth."

5. Continue to mark off each of the other distances you calculated in (2). Label each to show the period or epoch represented.

6. Now mark and label other events listed on your time scale.

7. Explain why you cannot mark the position of important events in history, such as the American Revolution, on the paper tape.

8. Would it be possible to measure a distance on the tape which would represent the length of a person's lifetime? Explain your answer.

Chapter 5

ACTIVITY 5.1: Mineral-forming Environments

Objective: To review and relate mineral forming environments and rock forming environments to mineral resource exploration.

Materials: Text, (Chapter 3, part III, and Chapter 4, Part III, D & E, IV D, writing instrument, and this activity.

Procedure: Using the knowledge (and your text) of the formative environments of various mineral resources, describe the kind of geologic characteristics you would be looking for if prospecting for the following mineral resources. Include both the rock and mineral forming environment if needed (may be more than one).

1. Iron

2. Gold

3. Coal

4. Marble

5. Limestone

ACTIVITY 5.2: Mineral Resource Report - Group Project

Objectives: To research and develop a packet of information on a specific mineral resource.
To develop skills in organization and composition of technical information.
To present that information in an oral format to the class.

Materials: Mineral resource books and articles, notecards, paper, neatness and organization pill, and writing device.

Procedure: After your group has been assigned a specific mineral resource, your group will gather information about the following aspects of that mineral resource.

a. Geological Occurrence

b. Location
    1. U. S. } ---- Mining Regions
    2. World }

c. Exploration Techniques

d. Mining Techniques

e. Milling (processing) Techniques

f. Uses

g. Problems
    1. Environmental
    2. Economic

h. Future Outlook

When you have gathered the information on notecards, organize it in an outline format. You may use the one above, but be sure it is complete enough to give myself and others all the important facts under each heading. Include, with your outline, at least one map or diagram relating to some aspect of the report. In addition to the report itself, include a bibliography page listing your sources of information.

Finally, the group is responsible for a brief (10-15 minute) presentation to the class about what you have learned about the resource.

GRADE: Your grade will be based on a composite of research work, quality of the paper and on the oral presentation.

NOTE: Each student in the class is responsible for filling out a Mineral Resource Review Sheet on the presenting group.

NAME ____________________
HOUR ____________________

Chapter 5

ACTIVITY 5.2: Mineral Resource Report - Group Project (continued)

Mineral Resource Review Sheet

Mineral(s) Name: ____________________
____

Presentation Group Names:
____
____
____
____

Geological Occurrence:

Location:

Exploration:

Mining Techniques:

Milling Techniques:

Uses:

Problems:

Future:

Please rate the following from 1 (BOO!) to 5(YEA!).
Presentation Information:

Presentation Organization:

Overall Presentation:

ACTIVITY 6.1: Map Comparison

Objective: To determine different map features and uses.

Materials: Maps numbered 1 through 6 and writing instrument.

Procedure: The numbers below correspond to the map numbers. Answer the following questions about each map.

1. a. What is the name of the map?

   b. In general, what kinds of features are shown?

   c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

2. a. What is the name of the map?

   b. In general, what kinds of features are shown?

   c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

(over)

ACTIVITY 6.1: Map Comparison (continued)

3. a. What is the name of the map?

   b. In general, what kinds of features are shown?

   c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

4. a. What is the name of the map?

   b. In general, what kinds of features are shown?

   c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

5. a. What is the name of the map?

   b. In general, what kinds of features are shown?

ACTIVITY 6.1: Map Comparison (continued)

5. c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

6. a. What is the name of the map?

   b. In general, what kinds of features are shown?

   c. What would be the major uses for this map?

   d. Who would be most likely to use this map?

   e. If you wanted a copy of this map, where could you obtain one?

After looking at all the maps, do you see any information that all the maps have in common? List them, and explain why all maps need that information.

Chapter 6

ACTIVITY 6.2: Orange Peel Special OR Yes, Chris, the World Is Flat!

Objective: To demonstrate the problems in creating map projections of the earth's surface.

Materials: Orange, piece of paper, pencil, and permanent marker pen.

Procedure: Follow the directions below.

1. Draw a likeness of the continents on an orange.
2. Carefully remove the skin from the orange in as few pieces as possible. Got it? Flatten the skin on the desk. What problems did you encounter?
3. Trace the outline of your orange peel onto a piece of paper, and add the remains of your continents.
4. Describe the problems you encountered in making a spherical-shaped object into a flat object.
5. How does this relate to making map projections of the earth?
6. Now you may eat the earth's interior!!

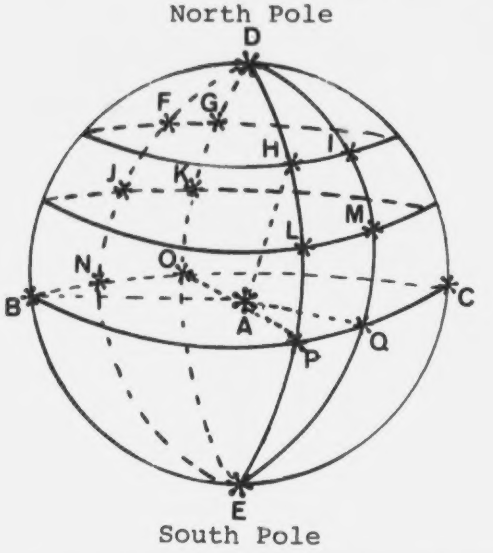
ACTIVITY 6.3: Latitude and Longitude

Objective: To relate the earth (a sphere or actually an oblate spherical) to the determination of longitude and latitude values or degrees.

Materials: Text, activity sheet, 3-D brain waves and writing device.

Procedure: Using the information and diagram below the student (you) are to complete the chart by filling in the latitude and longitude degrees for each point, B through Q.

HINTS:
1. Know the maximum number of degrees in both latitude and longitude.
2. Remember that opposite angles are equal.
3. Label degrees north, south, east, and west.



Angle BAO represents 70°

Angle PAQ represents 40°

Angle PAH represents 80°

Solid line DIMQE is the Prime Meridian

Point A is the center of the earth

Point L is 40° north latitude

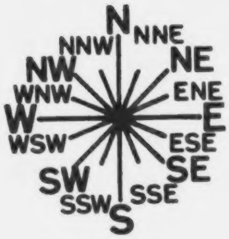
POINT	LATITUDE	LONGITUDE	POINT	LATITUDE	LONGITUDE
B			J		
C			K		
D			L		
E			M		
F			N		
G			O		
H			P		
I			Q		

ACTIVITY 6.4: Compass Direction

Objective: To determine compass directions from a given amount of information.

Materials: Information below and writing instrument.

Procedure: Below are several situations in which only the north direction is given. Fill in the blanks after you determine the other three directions.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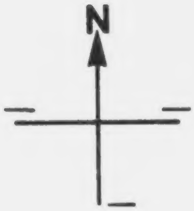
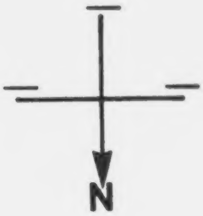
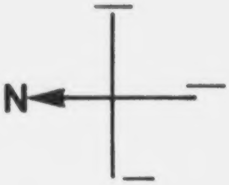
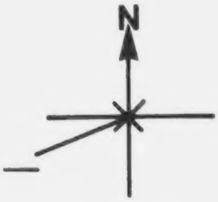
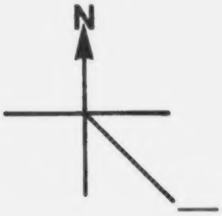
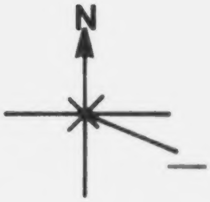


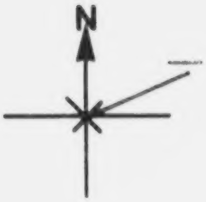


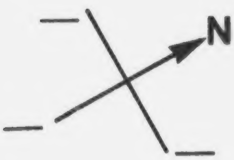


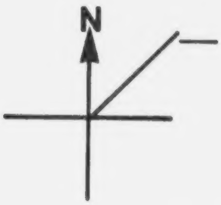


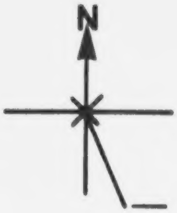


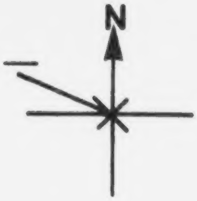












ACTIVITY 6:5 Scale

Objective: To relate the different scales to each other and to distances on the ground.

Materials: Text material and writing instrument.

Procedure: Follow the instructions below.

1. Fill in the blanks.

The map scale is the ratio between a distance on a ______________ and the same distance on the ________________ surface. If a map scale is 1 inch to 1 mile, that means that 1 inch on the _________________equals 1 mile on the _____________________ surface. Map scales may be shown in three ways: as a verbal scale, such as ______________________________; as a fractional scale, such as ______________________________; or as a graphic scale, such as ______________________________.

2. On USGS (United States Geological Survey) maps, standard scales are used depending upon the map size. Complete the following chart. **The USGS rounds actual inches per mile off. So your verbal scale will read approx.: 1 mile, 2 mile, etc.**

Measures

12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 mile

Fractional Scale	Verbal Scale	Graphic Scale
1:62,500	1"=	
1:125,000	1"=	
1:250,000	1"=	
1:24,000	1"=	

ACTIVITY 6.6: Distance

Objective: To measure distance on a map.

Materials: 100 Map Book by Hubbard, edge of paper, string, writing device.

Procedure: To measure distances on a map using a graphic scale is quite simple. First, find the graphic scale, (usually at bottom of map). Then, take a piece of paper or string and mark the distance to be measured on the paper. Hold the paper along the scale starting at one mark and measure the distance to the other mark NOTE: be careful to note where the 0 is on the scale and the scale distance to the left is for adding distances smaller than a mile. (Usually in 1/10's)

1. p. 12, Antelope Peak, Arizona - Distance of four lane highway running east, west across map ________________________.

2. p. 17, Bray, Calif. - Distance from summit of Orr Mountain to summit of Cedar Mountain (Summits marked with an △ ________________________.

3. p. 21, San Luis Rey, Calif. - Approximate length of Buena Vista Legran ________________________.

4. p. 24, Commerce City, Colo. - Length of South Platte River shown on map ________________________.

5. p. 31, Lake Wales, Florida - Approximate length of shareline around Lake Wales ________________________.

ACTIVITY 6.7: Distance and Direction (Metes and Bounds)

Objective: To describe an area using distance and direction or metes and bounds.

Materials: An area to describe, legs, paper, compass, (or sense of direction), and writing instrument.

Procedure: Using the metes and bounds method of area description, describe your home lot. **See Chapter 6 V Fla for example of description.**

After you have written your description, list some problems that might be encountered using this system for boundary location.

Metes and bounds description of your home lot, acreage, or other bounded area.

Problems in using the metes and bounds system.

ACTIVITY 6.8: Township and Range (general)

Objective: To locate designated areas using township and range method.

Materials: Grid below and writing instrument.

Procedure: Using the township and range method, locate W, X, Y, and Z on the grid below.

R4W	R3W	R2W	R1W	R1E	R2E	R3E	R4E
T3N				W			
T2N		X					
T1N							
T1S							
T2S						Y	
T3S	Z						

W = T._____, R._____

X = T._____, R._____

Y = T._____, R._____

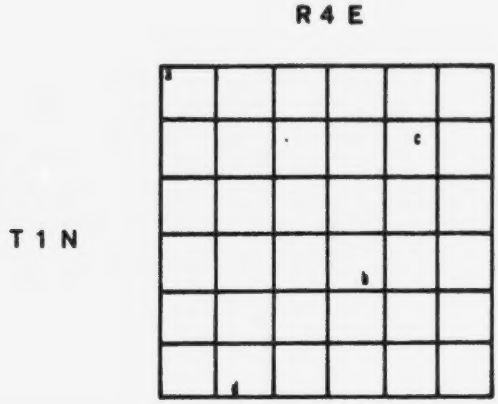
Z = T._____, R._____

ACTIVITY 6.9: Section Location

Objective: To locate designated areas within a section.

Materials: Township grid below and writing instrument.

Procedure: Below is one township (one of the squares in the grid in ACTIVITY 6.6) with small letters located within it. Give the specific location down to the nearest 40 acres.



a = T._____,R._____,Sec._____,_____¼,_____¼

b = T._____,R._____,Sec._____,_____¼,_____¼

c = T._____,R._____,Sec._____,_____¼,_____¼

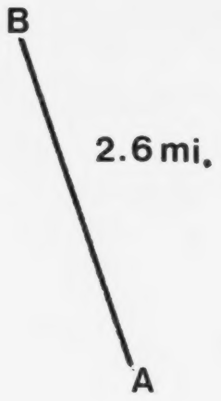
d = T._____,R._____,Sec._____,_____¼,_____¼

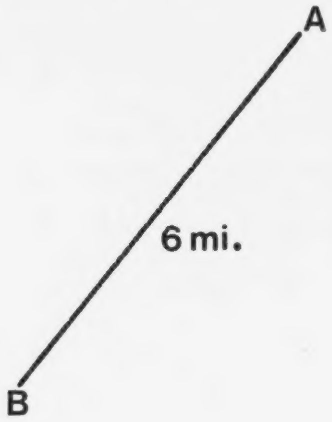
ACTIVITY 6.10: Point Location of Physical Landmarks

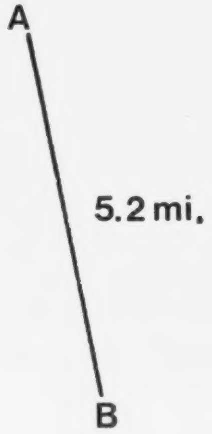
Objective: To do point descriptions of physical landmarks.

Materials: Physical landmarks, compass, and writing instrument.

Procedure: Using the locations of points and compass, write point locations for each example.

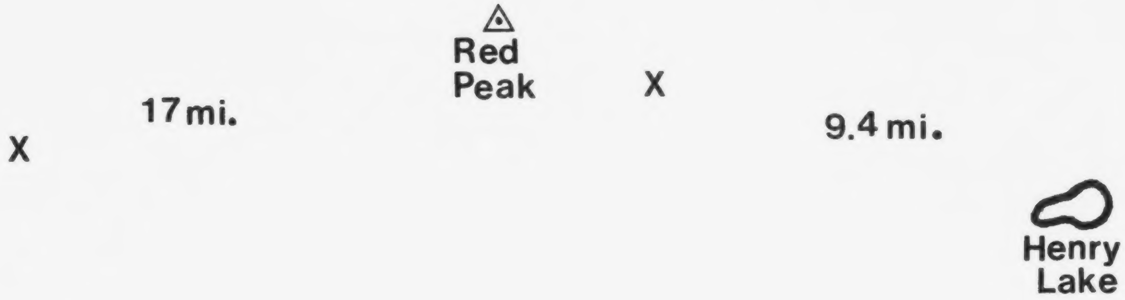






1 ______________________ 2 ______________________ 3 ______________________

A. is the starting point in 1,2, and 3.


Red
Peak
17 mi.
X
X
9.4 mi.
Henry
Lake

4 ______________________ 5 ______________________

X is the starting point in 4 and 5.

ACTIVITY 6.11: Latitude and Longitude

Objective: To identify latitude and longitude and to locate specific points on the earth using latitude and longitude.

Materials: Writing instrument, ACTIVITY 6.11 United States map, and ACTIVITY 6.11 chart.

Part 1

Procedure: Fill in the blanks.

Meridians are a series of lines that extend__________ and __________ and measure the distance of longitude ____________ and _____________. Parallels are a series of lines that extend __________ and _________ and measure the distance of latitude ___________ and ___________. Together, they form a grid pattern that can be used to locate specific points on the earth's surface. Both are measured in degrees, ___________________, and seconds.

Part 2

Procedure: In this activity, you are to locate the numbered points on the United States map located on page 62 , by their latitude and longitude. If possible, carry them to the nearest minute. Be sure to include the direction with the degrees. Fill in the chart on the top of page 61 with your information.

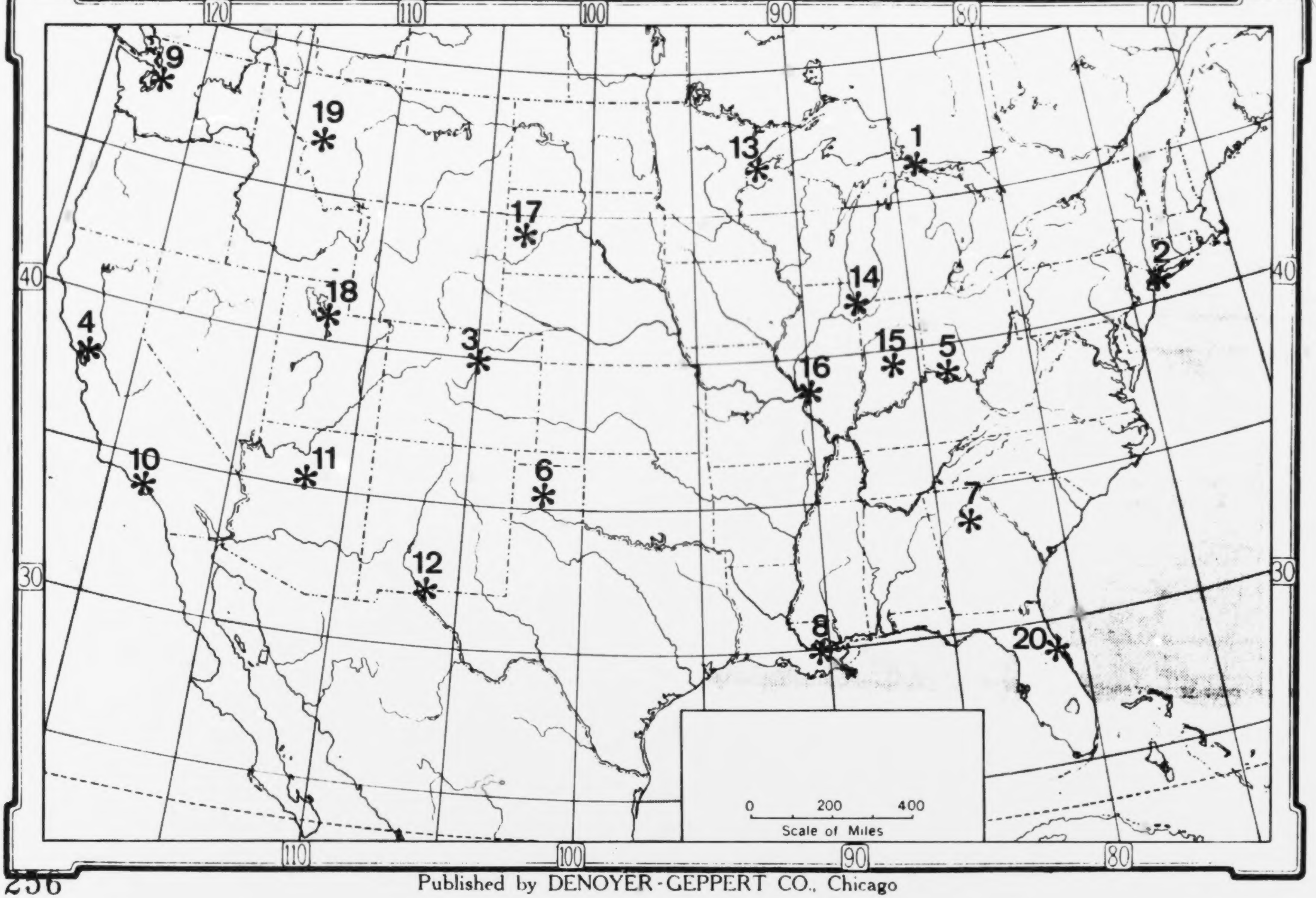
(over)

ACTIVITY 6.11: Latitude and Longitude (continued)

Latitude	Longitude	Latitude	Longitude
1.		11.	
2.		12.	
3.		13.	
4.		14.	
5.		15.	
6.		16.	
7.		17.	
8.		18.	
9.		19.	
10.		20.	

Bonus: By knowing only a series of latitude and/or longitude degrees, i.e., $\underset{76}{\overset{78}{77}}$----101-100-99---how can you tell whether you are east or west of the Prime Meridian and north or south of the equator?

Cartocraft Desk Outline Map, United States No. 7001 f s d


120
110
100
90
80
70
40
30
9
19
13
1
17
2
14
18
4
3
15
5
16
10
11
6
7
12
8
20
0
200
400
Scale of Miles
110
100
90
80

Published by DENOYER-GEPPERT CO., Chicago

Source map: © Denoyer-Geppert Company

ACTIVITY 6.12: Plane Coordinates

Objective: To locate points or areas using the plane coordinate system (also known as a grid system).

Materials: Text, activity sheet and writing instrument.

Procedure: Using the grid below, write the letter, number combinations to locate the numbered points.

	1	2	3	4	5	6	7	8
A								
B						1		
C		2		6				
D								4
E				9				
F	10						3	
G		5						8
H				7				

Grid Location Answers:

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________
9. __________
10. __________

ACTIVITY 6.13: Interpreting Contour Lines

Objective: To interpret topography from contour lines on a map.

Materials: Map on the following page and writing instrument.

Procedure: Referring to the contour map on the next page, answer the following questions.

1. What is the contour interval of the map? ____________________

   How did you determine this? ______________________________

   ____

2. Which side of the Nile River is steeper? ____________________

   How can you tell this? ______________________________

3. How many hilltops are on the map? __________ How is a hilltop represented? ______________________________

4. What is the feature at D? ______________________________

5. Give the elevations for the points listed by letter. (If the letter is on the contour line, give the exact elevation; if it is between, give the minimum and maximum, e.g., 721-739.)

   A ________________ D ________________ G ________________

   B ________________ E ________________ H ________________

   C ________________ F ________________ I ________________

6. Which direction do the following streams flow? (general trend)

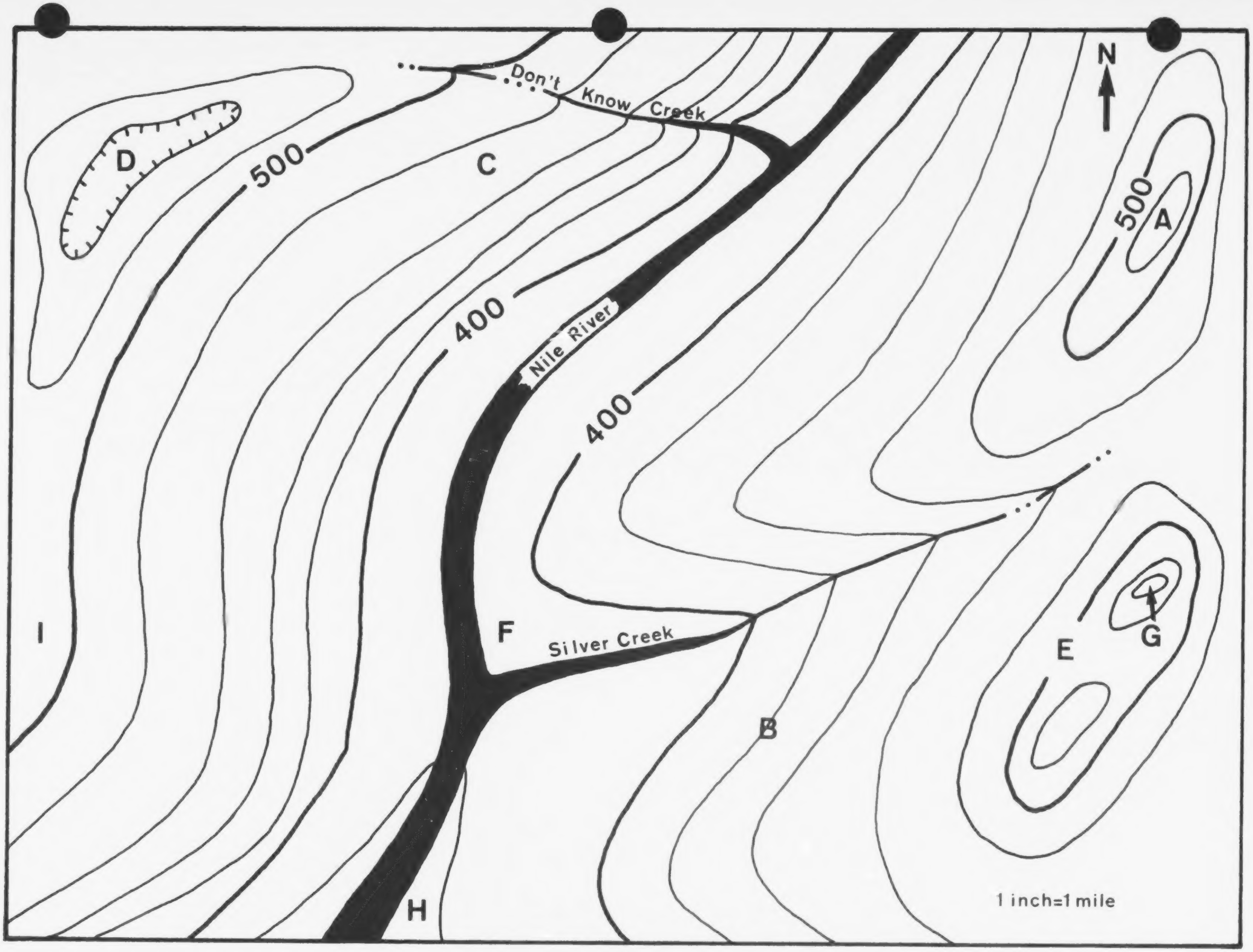
   Silver Creek ________________________

   Nile River ________________________

   Don't Know Creek ________________________

   Which rule did you use to determine these directions? ________

   ____


Don't Know Creek
N
D
500
C
500
A
400
Nile River
400
I
F
Silver Creek
E
G
B
H
1 inch=1 mile

ACTIVITY 6.14: Contour Map Profile

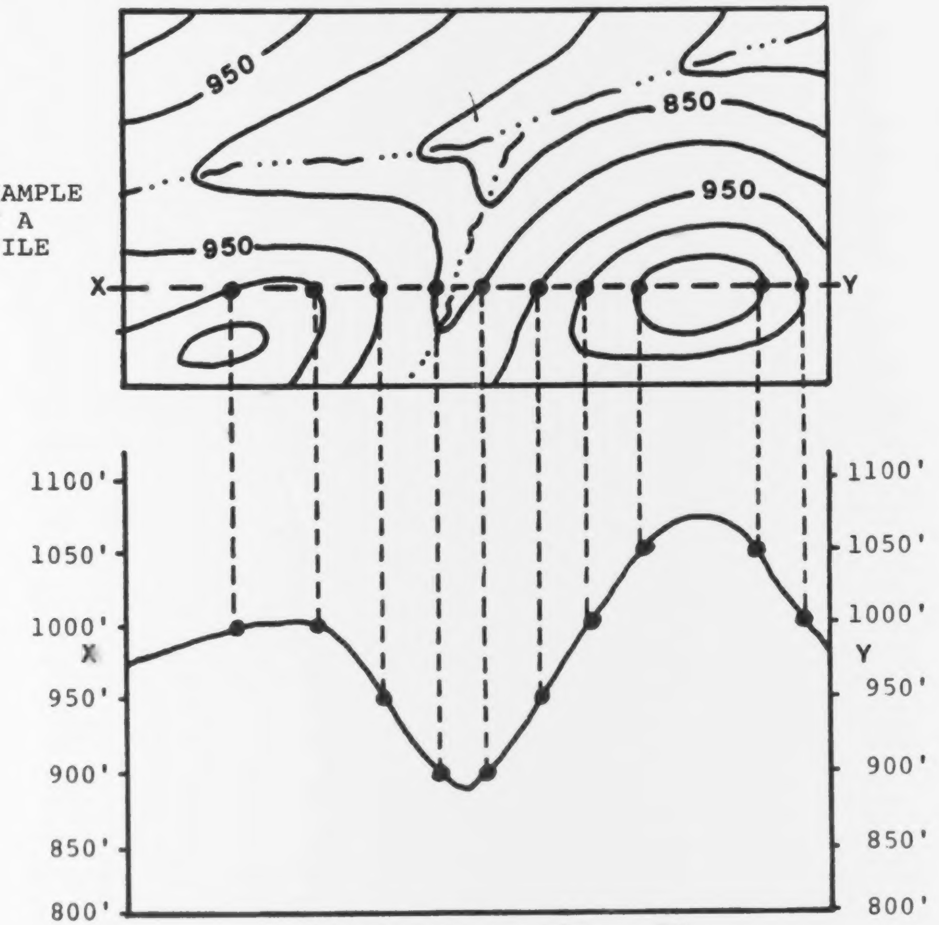
Objective: To draw a profile of a contour map.

Materials: Three strips of paper, text information, writing instrument, and ACTIVITY 6.12 figures.

Procedure: To draw a profile, follow the instructions below.

Map Scale: 1" = 570 feet

AN EXAMPLE OF A PROFILE



Vertical Exaggeration = 5X

1. On the contour map for this activity (on the next page), there are three straight lines labeled AB, CD, and EF. Mark the elevation of each point where a contour line crosses a straight line.

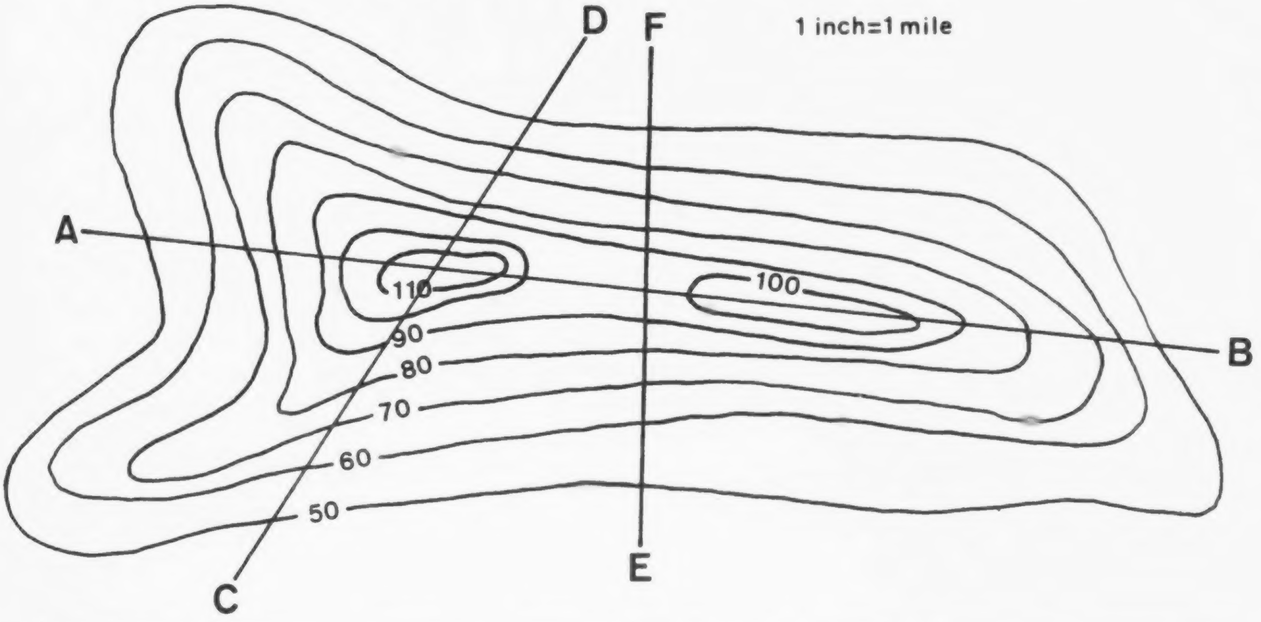
(over)

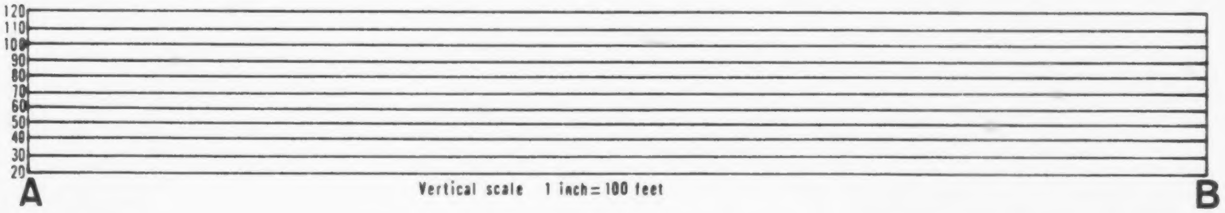
ACTIVITY 6.14: Contour Map Profile (continued)

2. Place the edge of one of your strips of paper along the line from A to B. Make a mark on your strip of paper wherever the edge of the paper crosses a contour, and label the elevation of the contour. Also, indicate the ends of AB. Repeat this process for lines CD and EF.

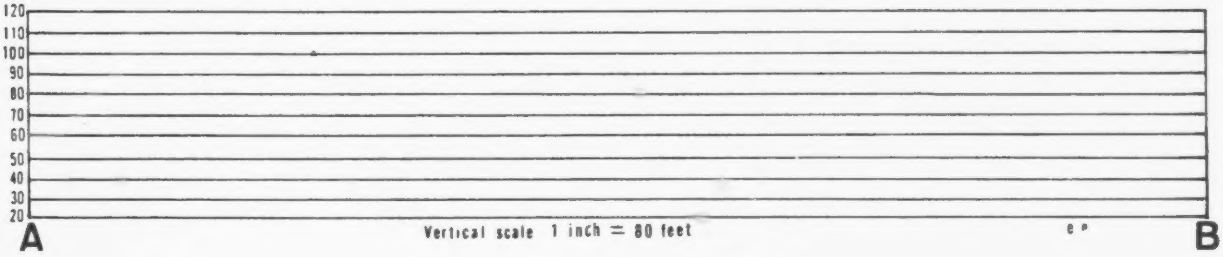
3. Transfer the points on each paper strip onto the two vertical scales labeled for each line. Plot the elevations by drawing vertical lines from the points down to their corresponding elevations.

4. Connect the elevation points with a smooth, curved line to complete your profile.


D
F
1 inch=1 mile
A
110
100
90
80
70
60
50
B
E
C

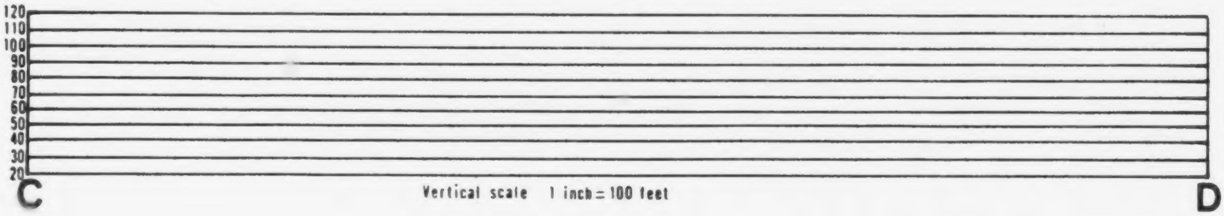

120
110
100
90
80
70
60
50
40
30
20
A
B

Vertical scale 1 inch=100 feet

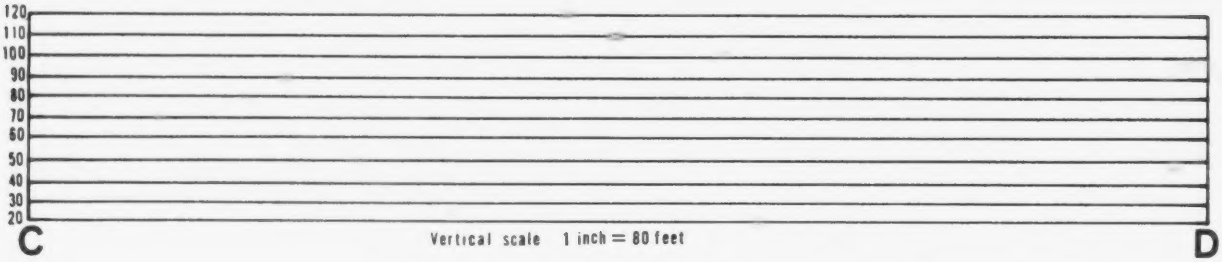

120
110
100
90
80
70
60
50
40
30
20
A
B

Vertical scale 1 inch = 80 feet

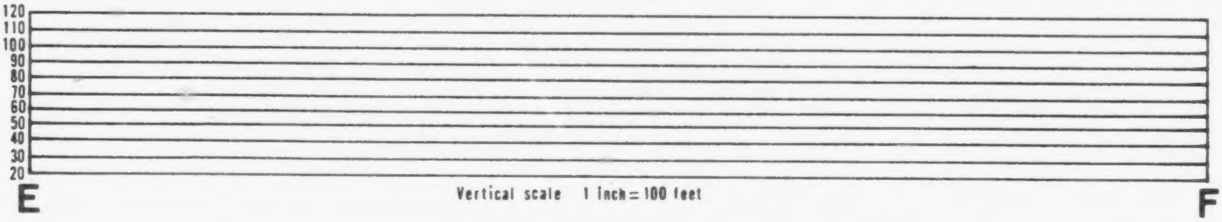
ACTIVITY 6.14: Contour Map Profile (continued)



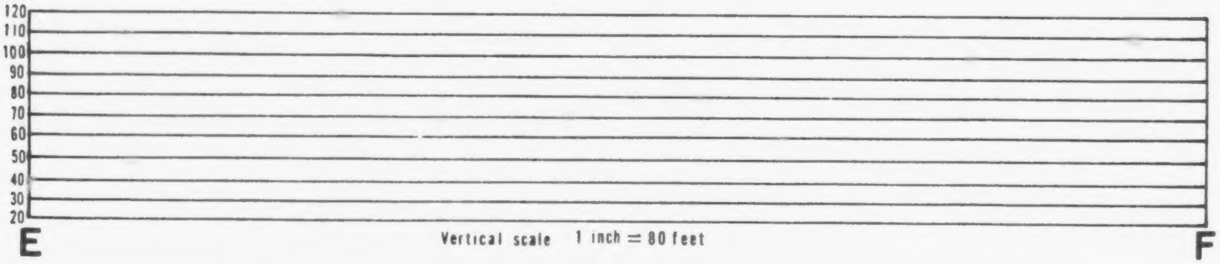
Vertical scale 1 inch = 100 feet



Vertical scale 1 inch = 80 feet



Vertical scale 1 inch = 100 feet



Vertical scale 1 inch = 80 feet

P.S. There is more on the next page!

ACTIVITY 6.14: Contour Map Profile (continued)

Answer the following questions.

1. What is the maximum relief, in feet, along lines AB, CD, and EF?

   line AB __________

   line CD __________

   line EF __________

2. What is the distance, to the nearest mile, along the entire length of lines AB, CD, and EF?

   line AB __________

   line CD __________

   line EF __________

3. Using the formula given in the text, calculate the exaggeration of the vertical scale of your profiles.

4. If you wished to reduce or increase the vertical exaggeration of your profile, how would you do it?

5. What is the benefit of vertical exaggeration?

ACTIVITY 6.15: Gradient Problems

Objective: To calculate the gradient of various points in given situations.

Materials: Writing instrument.

Procedure: Using the formula below, calculate the gradient in the following problems.

$$\text{Gradient} = \frac{\text{Difference in elevation between points}}{\text{Straight line difference between points}}$$

1. The distance between two points is 4 miles, and the difference in elevation is 30 feet.

2. The distance between two points is ½ mile, and the difference in elevation is 30 feet.

3. The distance between two points is 0.7 miles, and the difference in elevation is 150 feet.

4. The difference in elevation is 95 feet, and the distance between two points is 2.46 miles.

5. The difference in elevation is 0, and the distance between two points is 0.28751 miles.

ACTIVITY 6.16: Township and Range (specific)

Objective: To locate specific points using the township and range method.

Materials: Whitewater, Wisconsin topographic map and writing instrument.

Procedure: Look at the Whitewater, Wisconsin map. Answer the following questions. Try to visualize the section divisions to aid you in subdividing the various units.

Identify the feature found at the following locations.

1. T6N, R15E, Sec. 26, NE¼ ______________________________
2. T6N, R15E, Sec. 25, NW¼ ______________________________
3. T5N, R17E, Sec. 7, SW¼ ______________________________
4. T4N, R16E, Sec. 12, SW¼ ______________________________
5. T6N, R16E, Sec. 34, NE¼ ______________________________

Describe the following locations. (Refer to the map on the wall for help in finding general locations.)

6. Corner Grove School (west of Palmyra about 2 inches)

   T._____, R._____, Sec._____, _____¼

7. Siloam Chapel Cemetery (southeast of Oak Hill about 2 inches)

   T._____, R._____, Sec._____, _____¼

8. Fish Hatchery (east of Whitewater about 3 inches)

   T._____, R._____, Sec._____, _____¼

9. Wayside Park (southeast of Whitewater about 4 inches on Route 12)

   T._____, R._____, Sec._____, _____¼, _____¼

10. South Heart Prairie School (east of Whitewater Lake about 2 inches)

    T._____, R._____, Sec._____, _____¼, _____¼

ACTIVITY 6.17: Latitude and Longitude Grid (Rectangular System)

Objective: To use the latitude and longitude grid method (rectangular system) to locate specific points on topographic maps.

Materials: Boothbay, Maine topographic map and writing instrument.

Procedure: Using the Boothbay, Maine topographic map, follow the instructions below.

Locate the following places by the latitude and longitude grid system.

1. The town of Pemaquid Point (right center) ____________________
2. Pools Landing (east of East Edgecomb in the upper center) ____________________
3. Fort Edgecomb (upper center) ____________________
4. Squirrel Island (lower center) ____________________
5. Blue Star Memorial Highway (upper left) ____________________
6. Smith Hill (center) ____________________
7. Outer Heron Island (lower center) ____________________
8. Bristol Mills (upper right) ____________________
9. Oak Island (upper left) ____________________
10. Outer Head (lower left) ____________________

Answer the following questions.

11. What is the uppermost latitude of the map?________________
12. What is the lowermost latitude of the map?________________

(over)

ACTIVITY 6.17: Latitude and Longitude Grid (continued)

13. What is the right longitude of the map?_______________________

14. What is the left longitude of the map?________________________

15. If the map contains the same number of minutes of latitude and longitude, why is it not square?

____

ACTIVITY 6.18: Letter and Number Grid

Objective: To use the letter and number grid method to locate specific points.

Materials: 100 Topographic Maps and writing instrument.

Procedure: Using the 100 Topographic Maps book, follow the instructions below.

Turn to the indicated pages, and name the major feature located by the grid system.

1. p. 13 B2 ____________________
2. p. 14 D4 ____________________
3. p. 17 E5 ____________________
4. p. 27 A3 ____________________
5. p. 35 C2 ____________________

Use the grid system to locate the following features on the indicated pages. Use compass direction also, if necessary.

6. p. 39 Ely Gap ____________
7. p. 44 South Turner Mountain ____________
8. p. 47 Harvard University Observatory ____________
9. p. 50 Clear Lake ____________
10. p. 53 Mine Dump ____________

For more specific directions, use compass directions within the number and letter grid. For example, on page 55, there is a bench mark of 703 in the northwest corner of E4 (E4, NW). Name the feature found on the following pages.

11. p. 59 C1, NC ____________________

(over)

ACTIVITY 6.18: Letter and Number Grid (continued)

12. p. 60 B2, SC ______________________________

13. p. 63 C4, SE ______________________________

14. p. 65 A4, SE ______________________________

15. p. 68 E3, C ______________________________

Using directions with the grid, locate the following features.

16. p. 71 Gilbert School ________________

17. p. 74 Westgaard Cemetery ________________

18. p. 75 Fallen Timbers State Memorial ________________

19. p. 76 Roberts University ________________

20. p. 79 Wizard Island ________________

ACTIVITY 6.19: Symbols

Objective: To identify map symbols on a topographic map.

Materials: Whitewater, Wisconsin topographic map; ACTIVITY 6.19 chart; USGS Map Symbols in 100 Topographic Maps; and writing instrument.

Procedure: Review the various symbols using Map Symbols on page 10 of 100 Topographic Maps. Fill in the ACTIVITY 6.17 chart below, using the Whitewater, Wisconsin topographic map.

Name	Symbol	Location (by township, range, and section)
Marsh		
Railroad		
School		
Church		
Cemetery		
Bench Mark		
Power Line		
Gravel Pit		
Building		
County Boundary		
Heavy Duty or Primary Road		
Unimproved Road		

ACTIVITY 6.20: Interpreting Contour Lines on USGS Topographic Maps

Objective: To interpret landforms, shapes, and elevations from contour lines on USGS topographic maps.

Materials: Boothbay, Maine topographic map, 100 Topographic Maps, and writing instrument.

Procedure: Follow the instructions below.

1. As a review, define or explain the following:

    a. contour line

    b. contour interval

    c. closeness of contour lines

    d. hilltop appearance

    e. depression appearance

    f. rule of the V's

BOOTHBAY, MAINE

Using the Boothbay, Maine topographic map, answer the following questions:

2. What is the contour interval of the map? ____________________

3. What is the maximum elevation of Smith Hill (R5 NW)?

    ____

4. Between which two contours does Lower Pond (R3 NE) lie?

    ____

5. What is the elevation of Wolf Pond (R1 NW)? ____________________

6. What is the minimum to maximum elevation of Cape Island (R8 WC)?

    ____

(over)

ACTIVITY 6.20: Interpreting Contour Lines on USGS Topographic Maps (continued)

7. Using the compass directions, state which side of the following landforms is steeper.

   a. Fort Island (R5 NE) ____________________

   b. Barters Island (R1 SE, R4 NE) ____________________

   c. High Island (R6 NC) ____________________

   d. Doggard Point (R1 SW, R4 NW) ____________________

Using the 100 Topographic Maps book, answer the following questions.

8. p. 25: Holy Cross, Colorado
   p. 28: Little Creek, Delaware
   a) What are the contour intervals of these two maps.

   b) Why do you think different intervals were used on these maps?

9. p. 31: Lake Wales, Florida
   a) In what kind of topographic feature are most of the lakes on this map located?

   b) How did you determine this?

10. p. 34: Thousand Springs, Idaho
    The Snake River flows through a steep canyon. How do the contour lines represent this?

11. p. 43: South Pass, Louisiana
    This map does not have a contour interval listed.
    Why not?

12. Describe the general topography (shape) of the land on the following maps. (hilly, flat, hills and valleys, etc.)
    a) p. 16: Waldron, Arkansas

    b) p. 17: Bray, California

    c) p. 24: Commerce City, Colorado

    d) p. 56: Ironton, Missouri

ACTIVITY 6.20: Interpreting Contour Lines on USGS Topographic Maps (continued)

e) p. 57: Chief Mountain, Montana

f) p. 70: Mount Mitchell, North Carolina

g) p. 107: Alma, Wisconsin/Minnesota

13. On the following maps, give the general direction that each stream flows.

a) p. 15: St. Paul, Arkansas

Thomas Creek (A5) ____________________

Dabney Creek (B5) ____________________

Possum Creek (C4, D4) ____________________

b) p. 35: Effingham, Illinois

Blue Point Creek (E2, E3) ____________________

Little Wabash River (A5 to E4) ____________________

c) p. 82: Renovo West, Pennsylvania

Fish Dam Run (E4) ____________________

Shintown Run (A3, A4, B4, B5, C5) ____________________

Owl Hollow (B2) ____________________

d) p. 23: Anvil Points, Colorado

Balzac Gulch (E2, D2, C2) ____________________

Anvil Creek (A1, B2) ____________________

e) p. 39: Ewing, Kentucky/Virginia

Indian Creek (E1, D2. D3) ____________________

Poor Valley Branch (D3, C4, C5) ____________________

14. Determine the following distances. Measure to the nearest 1/10 mile.

a) p. 31: Lake Wales, Florida

Atlantic Coast Railroad (A2 to E5) ____________________

Canal (D1 to E1) ____________________

b) p. 49: Provincetown, Massachusetts

Dike (D2 to E3) ____________________

c) p. 79: Crater Lake, Oregon

Width of Crater Lake from Eagle Point to Pumice Point

____

ACTIVITY 6.20: Interpreting Contour Lines on USGS Topographic Maps (continued)

15. Give the minimum, maximum, or exact elevations of the following. The locations marked with a star (*) are to be exact elevations.

a) p. 47: Ayer, Massachusetts

Hilltop (B2 NW) ____________________

Depression (E3 C) ____________________

Hilltop (D4 C) ____________________

Grave (D1 NC) ____________________

*Building (D3 SE) ____________________

b) p. 69: Ticonderoga, New York

*Log Chapel (E2 SE) ____________________

Swamp (C4 WC) ____________________

Highest elevation of Route 22 (north-south road on center of map)

____

Lowest elevation of Route 22 ____________________

c) p. 82: Renovo West, Pennsylvania

Coal Hill (A5 NE) ____________________

Round Top Mountain (D2 EC) ____________________

d) p. 89: Rover, Tennessee

Versailles Knob (C2 NW) ____________________

Pope Cemetery (D2 C) ____________________

Hilltop (B4 NE) ____________________

ACTIVITY 6.21: Freehand Profiles

Objective: To draw freehand profiles of topographic maps.

Materials: 100 Topographic Maps and writing instrument.

Procedure: By now, your abilities in perceiving three-dimensional topography should be developed to the point of looking at the map and visualizing a general picture of the shape of the land. To practice this, obtain a 100 Topographic Maps book from your instructor, and draw general profiles of the six listed maps below, found in the book. Label any features crossed by your profile. Do not worry about contour lines. All that is needed is a general shape of the landscape.

1. p. 50: Delaware, Michigan
   Draw a north-south profile along the range line through Bailey Pond.

2. p. 17: Bray, California
   Draw a north-south profile through Cedar Mountain.

3. p. 79: Crater Lake National Park, Oregon
   Draw an east-west profile across Crater Lake and through Wizard Island.

(over)

ACTIVITY 6.21: Freehand Profiles (continued)

4. p. 84: Rhode Island
   Draw a north-south profile through Bull Head Pond and Green Hill.

5. p. 53: Virginia, Minnesota
   Draw a northeast-southwest profile following the transmission line.

6. p. 107: Alma, Wisconsin/Minnesota
   Draw a northeast-southwest profile.

ACTIVITY 6.22: Topographic Map Review

Objective: To review all of the topographic map basics.

Materials: Whitewater, Wisconsin topographic map; O'Fallon, Illinois topographic map; and writing instrument.

Procedure: Follow the instructions below.

WHITEWATER, WISCONSIN

1. Look at some of the features found on the map. Notice that at each side and in the corners, there is a name in parenthesis, i.e. (DELAVAN). This is to tell you the name of the map next to the one you have. Name all of the adjacent maps.

   ____________ ____________ ____________

   ____________ ____________ ____________

   ____________ ____________

2. Along the map edges, you will find information in red ink giving various distances from the edge of this map. Give the distance to the following locations.

   Lake Geneva ____________ Janesville ____________

   Watertown ____________ Eagle ____________

3. Other information in the map margin includes the map size,

   which is ____________. The approximate location of

   this map relative to the whole state is ____________.

4. It is possible to get maps of this area in a different scale and size. Give that information.

   Scale ____________ Size ____________

   Map Names ____________ ____________

   ____________ ____________

5. At the bottom of the map, you will find the magnetic declination which gives the degrees of difference between the geographic North Pole and the magnetic North Pole. List any other information you find at the bottom of the map.

   ____

(over)

ACTIVITY 6.22: Topographic Map Review (continued)

6. Map colors are also standardized by the USGS. List what the following colors represent:

Black ____________ Brown ____________ Green ____________

Pink ____________ Purple ____________ Blue ____________

O'FALLON, ILLINOIS

Answer the following questions about the O'Fallon, Illinois topographic map.

7. What is the contour interval of the map? ____________

How can you tell? ____________________________

8. Give the elevations for the following places, minimum and maximum unless otherwise stated.

a. St. Johns Orphanage (R5 SC) ____________________

b. Miller Lake (R8 NW) ____________________

c. Airshaft (R5 SW) ____________________

d. Hilltop west of Oak Hill Cemetery (maximum) (R3 SE) ____________________

e. Water Tank (exact) (R3 SC) ____________________

9. Give the general directions the following streams flow.

a. Ogles Creek (R2 NC) ____________________

b. Engle Creek (R3 NE) ____________________

c. Richland Creek (R4, 5, 7) ____________________

d. Loop Creek (R8 SC) ____________________

Chapter 7

ACTIVITY 7.1: Stereo Photographs

Objective: To be able to use stereo photos and stereoscopes in the study of geology.

Materials: Aerial Stereo Photograph Book by Harold R. Wanless published by Hubbard Press, Stereoscopes this activity, and a writing device.

Procedure:

Part I - Read the Introduction and answer the following questions:

1. In addition to the stereo-aerial photos, what else does each photo have with it.

   a.

   b.

2. Name five (5) uses for aerial photography.

   a.

   b.

   c.

   d.

   e.

3. Why have some areas of the U.S. had photos taken every few years?

4. What determines the scale of an aerial photo?

   a.

   b.

5. What is stereoscopic vision?

(over)

ACTIVITY 7.1: Stereo Photographs (continued)

6. Explain how a stereo-photo is made.

7. How is a stereogram different from a stereo-photo?

8. What is the purpose of a stereoscope?

9. What is meant by the "vertical exaggeration" of a stereo-photo?

10. Explain how each of the following areas of study use aerial stereo-photos.
    - a. geology
    - b. soils
    - c. forestry
    - d. changes in natural processes.

ACTIVITY 7.1: Stereo Photographs (continued)

11. Explain how a stereoscope should be set up to use for stereograms.

Part II:

It usually takes some practice to be able to use stereo-photos. This part of the activity is for you to get that practice.

Set up the stereoscope and turn to page 50 (Mt. Capulin). Place your stereoscope on the stereogram as described in Part I question 11. You may have to rotate the stereoscope slightly to focus properly. Mt. Capulin should appear to rise upward from the desert floor and its crater should appear to be a dep depression.

For more practice, here is a list of stereograms that are useful.

page 4 - Sinkholes
page 10 - Crillon Glacier
page 16 - Half Dome
page 19 - Knob and Kettle
page 44 - The Loop
page 49 - Obey River
page 58 - Meteor Crater
page 88 - Mining
page 90 - Kalamazoo River
page 92 - Diamond Head

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GEOLOGY IS

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Geology Is

A Secondary Level Science Program

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Introduction to Students

What is GEOLOGY IS? It is a course in geology for high school students. The course is based upon the idea that the study of the earth is as important as any other natural or physical science in high school. The course emphasizes practical aspects of geology with a stress on environmental geology. It seeks to make an awareness of the relationships between the geoscience processes and the environment, and it encourages concern for the nation's well-being by applying expertise of scientific and technological nature to problems facing society.

The basic materials developed by the staff of GEOLOGY IS are a text and accompanying activity sheets specifically written for a secondary level geology course. The need for this text is thought to be basic to the lack of geologic education in the secondary school. No secondary text now exists for a full year geology course; the only available materials are earth science texts with geology sections or college level geology textbooks.

What will you study? This semester, you will look at the processes that affect the earth, both inside and outside. Unit IV involves the study of the physical earth--the structure, the composition, and the forces that affect it. You will study such topics as structure of the earth, plate tectonics, earthquakes, volcanic activity, mountain building, plains and plateaus, and the interrelationships of these processes.

UNIT V includes the study of the forces that affect the earth's surface--water, ice, and wind, for example. Again, as in UNIT IV, the various geologic forces and agents are related to one another to show various relationships.

Within each chapter, following a chapter outline is a list of Related Activities that will be used for that chapter. Geo Facts follow the related activities in every chapter. They are simply trivia concerning the topic of the chapter that you may find interesting. You will next notice a list of terms including Geologic Terms followed by Straight Terms. The Geologic Terms are titled differently in each chapter, and each title related to some subject within the specific chapter. The Straight Terms are those words we feel should be understood by any high school student. Now, you might say to yourself, "Self, how do I find the definitions of these Straight Terms?" Try a dictionary (but not for the Geologic Terms). At the end of each chapter, you will find a series of problems and questions. Answers to them are sometimes not found "word for word" in the text. They are designed to make you take the information you read and apply some thinking (Oh, no!) of your own.

In a separate booklet, there are various activity sheets. These will guide you through laboratory activities or will deal with topographic maps and aerial photographs. For each activity, you are given a description which includes the objective (purpose), materials (even including pencils!), and procedure. You are to answer the questions and occasionally provide conclusions.

GOOD LUCK!

Geologic Time Scale

ERA	PERIOD	EPOCH	ORIGIN OF NAMES	HISTORY OF LIFE	IMPORTANT GEOLOGIC EVENTS
CENOZOIC (Age of Recent Life)	QUATERNARY	Recent (Holocene) (10,000)		Man dominant. Domestic animals develop.	Widespread glaciation. Great Lakes form.
		Pleistocene (2,000,000)	From Greek meaning less recent; epoch has 20-40% modern species.	Early man. Elephants flourish in North America then die out.	Widespread glaciation.
	TERTIARY	Pliocene (11,000,000)	Tertiary names indicate the degree of relationship of fossil molluscs to those still alive. Pliocene means more recent, with 50-90% modern species. Miocene means less recent, 20-40%	Modern horse, camel, and elephant develop.	Major uplift of Rockies. Baja, Cal. separates from mainland, forming Gulf of California.
		Miocene (25,000,000)		Spread and development of grazing mammals. Horse migrates to Asia.	Mediterranean dries up. Growth of Himalayas. Red Sea opens. Africa moves up to create Alps.
		Oligocene (40,000,000)	From Greek meaning little recent with 10-15% modern species.	Earliest elephants. Monkeys die in North America.	Main Pacific Plate touches North America altering mountain formation in western U.S.
		Eocene (60,000,000)	From Greek meaning dawn, with 1-5% modern species.	First rhinoceroses and camels. Ancestors of modern horse.	Volcanoes in western U.S. Australia separates from Antarctica. India begins to ram Asia.
		Paleocene (70,000,000)	From Greek meaning ancient, with 0% modern species.	First primates and horses. New mammals develop.	Land bridge between Americas submerges. Rockies continue to develop from Cretaceous.
MESOZOIC (Age of Medieval Life)	CRETACEOUS (135,000,000)		From Latin word for chalk (creta) composing white cliffs along English Channel.	First flowering plants. Extinction of dinosaurs.	North America and Europe separate. India breaks from Australia and Antarctica. Andes form.
	JURASSIC (180,000,000)		Named for Jura Alps where these rocks were first studied.	Dinosaurs at their peak. First birds. More mammals.	North America and Africa move apart. Sierra Nevada batholiths forming.
	TRIASSIC (225,000,000)		From word "trias" indicating the three-fold character of these rocks in Europe.	First mammals. Reptiles thrive.	Ocean between Europe and Asia closes. Urals begin to form.
PALEOZOIC (Age of Ancient Life)	PERMIAN (270,000,000)		Named for ancient state of Permia, Russia where these rocks were first studied.	Mammal-like reptiles.	Ancient Atlantic Ocean completely closes. Pangaea formed.
	PENNSYLVANIAN (LATE CARBONIFEROUS) (305,000,000)		Named for the coal-rich rocks found in the state of Pennsylvania.	Spread of "coal" plants. Large insects.	Coal swamps in many parts of North America and Europe. Appalachians complete uplift.
	MISSISSIPPIAN (EARLY CARBONIFEROUS) (350,000,000)		Named for the Mississippi River valley where these rocks are well exposed.	Earliest reptiles. Forests of coal producing plants.	Widespread seas in North America. Mountains begin in southern North America.
	DEVONIAN (400,000,000)		Named for Devonshire county in England where these rocks were first studied.	Amphibians seek land. Fullest development of fishes.	Mountain building in New England and Canada. Interior of North America submerges.
	SILURIAN (440,000,000)		Named for Silures tribe of ancient Wales during Roman conquest.	First air-breathing animals. First land plants.	Salt and gypsum deserts in eastern U.S.
	ORDOVICIAN (500,000,000)		Named for Ordovices tribe of ancient Wales during Roman conquest.	First vertebrates (fish). Trilobites at peak development.	Ancient Atlantic Ocean begins to shrink. Over 60% of North America covered by seas.
	CAMBRIAN (600,000,000)		From Roman name for Wales (Cambria) where complex fossils were first studied.	First abundant animal fossils.	Sediment deposited in inland seas.
PRECAMBRIAN (4,500,000,000)			Name meaning all time before Cambrian.	Earliest plants. Marine invertebrates, a few with shells.	Complex igneous and metamorphic activity. Oldest dated rocks. Glaciation, probably worldwide.

Numbers refer to time in years since the beginning of the era, period, or epoch.

You will be responsible for the names of the eras, periods, and epochs.

UNIT CONTENTS

UNIT IV

Internal Processes

Chapter 8 Structure of the Earth
Chapter 9 Plate Tectonics
Chapter 10 Earthquakes
Chapter 11 Volcanic Activity
Chapter 12 Mountains
Chapter 13 Plains and Plateaus

MADE IN PANGAEA
INFERNAL INTERNAL MACHINE
Mountain Mover
Earthquake Shaker
Magma Maker
Plate Pusher
Plate Puller

Unit IV: Internal Processes

CHAPTER 8: Structure of the Earth

I. Introduction

II. Evidence of a Variable Interior
    A. Seismology
        1. Earthquake Waves
            a) Body Waves
                (1) Primary (P) Waves
                (2) Secondary (S) Waves
            b) Surface (L) Waves
            c) Free Oscillations
        2. Information from Seismic Waves
    B. Meteorites
    C. Specific Gravity
    D. Temperature
    E. Magnetism

III. Structure of the Earth
    A. Core
        1. Inner Core
        2. Outer Core
    B. Mantle
        1. Inner Mantle
        2. Outer Mantle
            a) Asthenosphere
            b) Lithosphere
    C. Crust
        1. Oceanic Crust
        2. Continental Crust
        3. Isostasy

IV. Summary

Related Activities

Vocabulary

Draw and label a diagram of the various layers of the earth's interior.

Problems and questions

Structure of the Earth Geo Facts

Until a couple of centuries ago, it was believed that the earth was a molten globe surrounded by a thin solid crust. Volcanoes were believed to be places where cracks in the crust permitted molten materials to escape. A vestige of this belief continues today in the expression "crust of the earth" for the earth's outermost layer.

]

Chapter 8: Word List

Terms

Asthenosphere
Body wave
Crust
Core
Discontinuity
Earthquake
Felsic
Focus
Free oscillation
Geothermal gradient
Internal processes
Isostasy
Lithosphere
Mafic
Mantle
Meteorite
Moho
Primary (P) wave
Secondary (S) wave
Seismic wave
Seismograph
Seismology
Shock wave
Shadow zone
Specific gravity
Surface (L) wave

Straight Terms

Alloy
Density
Diameter
Equilibrium
Hypothesis
Mobile
Oscillate
Radius
Reflect
Refract
Submarine
Validity
Vapor
Velocity

UNIT IV: INTERNAL PROCESSES

Chapter 8: Structure of the Earth

I. Introduction: Until now, you have studied geology that is observable on or near the surface of the earth. Unit IV is going to take you down under the surface where sometimes less obvious processes have been and are at work changing the character of the inside as well as the outside of the earth. These processes are called internal processes. Some result from the internal heat of the earth. Plate tectonics, earthquakes, volcanic activity, mountain formations, plains and plateaus are surface expressions of internal processes that you will be studying in the next five chapters. But first, the structure of the earth must be considered.

II. Evidence of a variable interior: It is extremely difficult to study the earth's interior. The only rocks and minerals available from below the crust are those taken from mines and bore holes (holes drilled into the earth for the purpose of drilling for oil or for other exploration). The deepest bore hole to date is a 10.6 kilometer (6.6 mi.) oil well in Siberia. The deepest mines extend downward only about 3 kilometers (2 mi.). Because the earth's radius is almost 6,400 kilometers (4,000 mi.), information about the deep interior from mines and bore holes is limited. Therefore, people must depend upon indirect clues.

   A. Seismology: This is the study of earthquakes. Through the years, seismologists have found that earthquake vibrations can be used like x-rays to make a cross-section of the earth's structure.

1. Earthquake waves: An earthquake is the trembling of the earth caused when large masses of rock suddenly fracture and move. An earthquake causes vibrations or shock waves, called seismic waves, to move through the earth in much the same way ripples are caused by dropping a pebble into quiet water. This wave energy is measured by an instrument called a seismograph. (See Figure 8.1) There are three different kinds of waves.

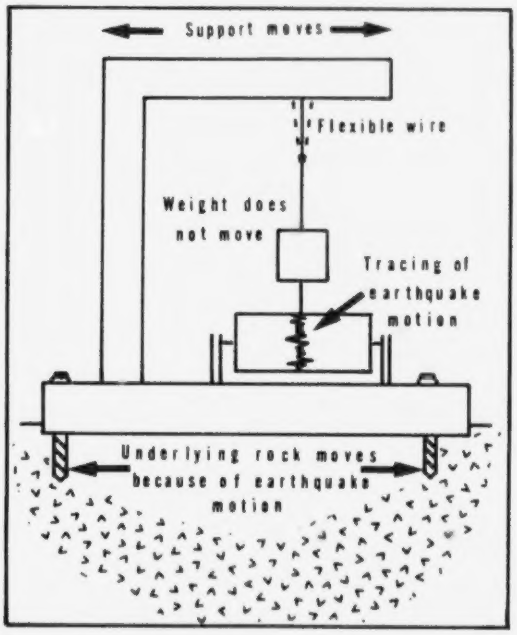

Support moves
Flexible wire
Weight does not move
Tracing of earthquake motion
Underlying rock moves because of earthquake motion

Figure 8.1. This diagram of a seismograph shows that earthquake waves cause the underlying rock and the attached support to move. The weight is fastened in a manner that keeps it from moving; therefore, it remains stationary while the pen records the earthquake motion.

a) Body waves: These waves travel from the source (or focus) of the earthquake, through the interior of the earth, then back to the earth's surface. Most of the information about the earth's interior comes from body waves of which there are two types.

(1) Primary (P) waves: These waves are able to travel through any state of matter--solid, liquid, or gas. The individual particles of material that are in the path of P-waves come together and separate (move forward and backward) in much the same way as a coil spring expands and contracts. (See Figure 8.2)

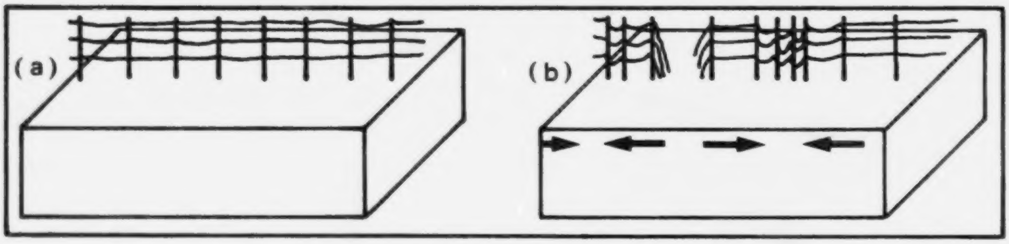


Figure 8.2. This diagram uses a straight line fence to illustrate the characteristic motion of a P-wave. (a) is the original fence before any seismic activity. (b) shows the results of the P-wave ground action.

(2) Secondary (S) waves: The particles in the path of S-waves are pulled sideways at right angles to the direction of wave motion. Their motion resembles the waves set up when a rope is shaken sideways. (See Figure 8.3)

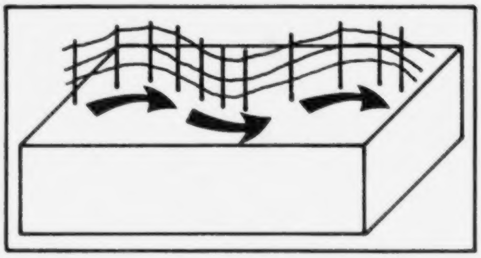


Figure 8.3. S-wave motion produces snake-like motion in the ground.

Because of the different motions, P- and S-waves travel at different speeds, with P-waves twice as fast as S-waves. The speed at which both types of waves travel depends upon the density and elasticity of the materials through which they travel. Travel is faster in more rigid material than in soft, plastic material. However, S-waves only go through solids and not liquids, so they cannot be picked up by seismographs on the opposite side of the earth from the focus of the earthquake. (See Figure 8.4)

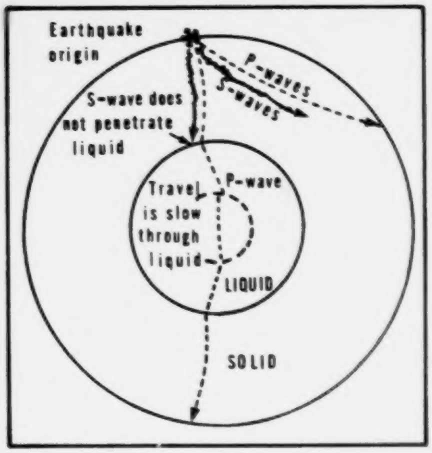

Earthquake origin
P-waves
S-waves
S-wave does not penetrate liquid
Travel is slow through liquid
P-wave
LIQUID
SOLID

Figure 8.4. A cross-section of the earth shows the influence characteristics of the materials through which the waves travel have on earthquake waves. S-waves will not go through liquids. P-waves will do so at a slower speed than through solids. In addition, P-waves travel faster than S-waves. The areas of the interior through which S- or P-waves do not travel are known as shadow zones.

b) Surface (L) waves: This is the second path followed by waves from the focus. Surface waves are generated by P- and S-waves and travel around the outermost layers of the earth like waves on water. (See Figure 8.5) They thereby provide information about the structure of the earth's outermost part. These waves are the ones that cause the destruction at the surface.

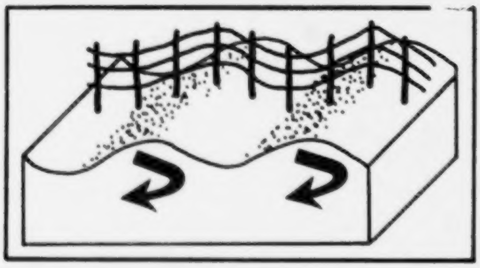


Figure 8.5. L-waves create a rippling motion.

c) Free oscillations: Caused only by the largest of earthquakes, these waves are vibrations of the earth as a whole, like a huge tub of jelly. They provide information about the outermost structure of the earth and a few independent clues about the interior.

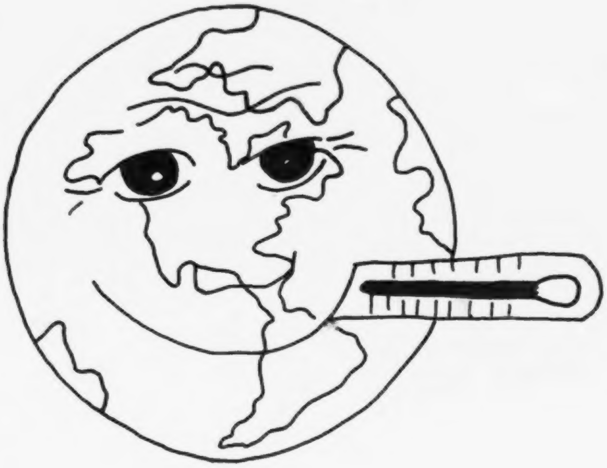
SEE ACTIVITY 8.1

2. Information from seismic waves: Because sound vibrations travel more rapidly through dense, more rigid material than through soft material, and because waves reflect and refract when they encounter boundaries between layers of different consistencies, seismologists have discovered that the materials of the earth's interior are not uniform in density and elasticity. From seismic information, scientists have been able to build a partial picture of the earth's interior.

B. Meteorites: Meteorites are naturally occurring, small, solid bodies that have fallen to the earth's surface from outer space. Evidence of the composition of the center of the earth may be provided by the composition of meteorites. Some scientists believe that they are fragments of a planet which broke up long ago. It is possible that iron-nickel meteorites are portions of a former planet's center, giving rise to the hypothesis that our own planet's center is of a similar iron-nickel composition.

C. Specific gravity: Specific gravity is the weight of an object compared to an equal volume of pure water. If one divides the mass of the earth by its volume, the density or specific gravity is 5.5. Surface rock has an average specific gravity of 3. It must be concluded that buried rocks must have greater specific gravities. Thus, another clue is provided about the earth's interior.

D. Temperature: The temperature of the earth increases with depth. This can be evidenced by the appearance of molten rock, steam, hot water, and vapors onto the earth's surface from an internal source. Other evidence is from mine temperatures and those taken in oil and gas wells. The increase in the earth's temperature with depth is known as the geothermal gradient. It is estimated to be 1 degree Centigrade for about every 27 meters (1 degree F per 50 ft). It is believed that about 20 percent of the interior heat remains from a warmer stage of existence. The remainder is from the radioactive heat of internal rocks.



E. Magnetism: The earth behaves like a huge magnet. Surface proof of this is that a compass needle points northward, lining up with the magnetic lines of force surrounding the earth. Measurements show that a large, main magnetic field exists deep within the earth. The earth's rotation causes the fluid iron near the center of the earth to move. The flowing liquid generates a main magnetic field. (See Figure 8.6)

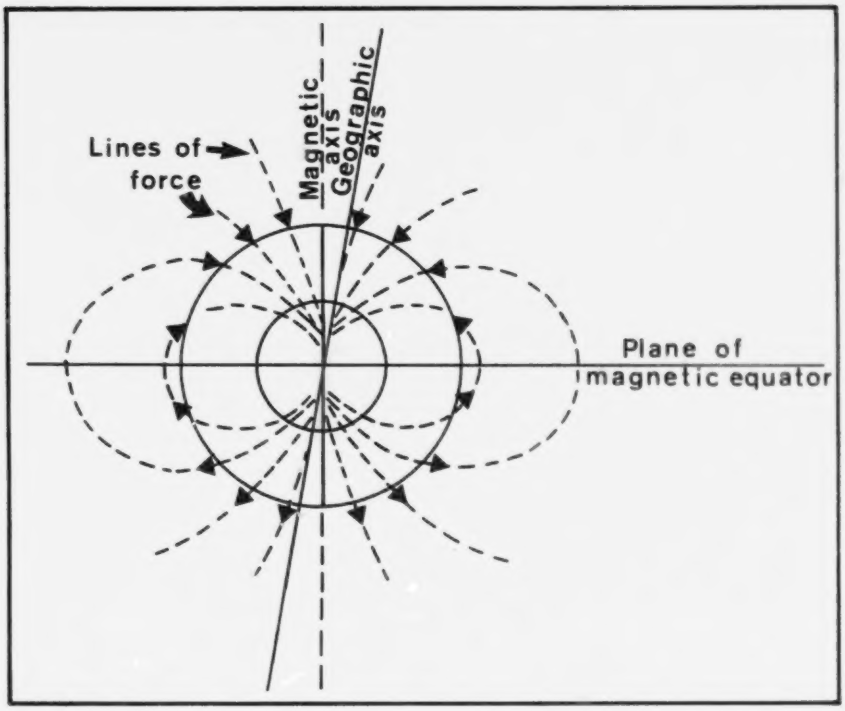


Figure 8.6. In this cross-section of the earth, the lines of force in the earth's magnetic field are shown passing through the magnetic axis. The arrows at the surface of the earth show the orientation of a compass needle that is free to move in space.

III. Structure of the earth: As was state before, it is difficult to study the earth's interior. However, by studying the various clues just discussed, scientists have formed hypotheses about the structure of the earth. The remainder of the chapter will discuss these hypotheses, starting with the innermost central core and progressing to the outermost crust. It is believed that there are 12 or more shells. They can be divided into three main portions.

A. Core: This is the central part of the earth. It has a radius of 3,475 kilometers (2,160 miles) and has approximately 16 percent of the earth's volume. Because the core has the greatest average specific gravity of any of the shells, an educated guess is that its composition is an iron-nickel alloy mixed with lighter elements. Until recently, evidence from iron meteorites seemed to verify this. However, new scientific evidence suggests it may be composed of the elements iron and sulfur, based on seismic and chemical indications. The core is believed to have two portions.

1. Inner core: It is believed that the inner core is solid--1,255 kilometers (780 mi) thick, hot--4,760°Centigrade (8,600°F), and dense--a specific gravity of 12 (compared to a density of one for water).

2. Outer core: The outer portion of the core blocks seismic S-waves and is therefore believed to be liquid. Cooler than the inner core, it has a temperature of 3,871° Centigrade (7,000°F), has a specific gravity ranging from 10 to 12.1, and is 2,220 kilometers (1,380 mi) thick.

B. Mantle: This layer constitutes about 80 percent of the total volume of the earth and is 2,900 kilometers (1,800 mi) thick. It is within this layer that the internal energy of the earth is released; therefore, it is of special interest. Clues to its composition have come from stony meteorites that are composed of silicate minerals. Like the core, the mantle also has two layers.

1. Inner mantle: This 2,576 kilometer (1,600 mi) thick layer is more rigid and more uniform in consistency than the outer mantle. It has a specific gravity ranging from 3.3 to 5.7 and has temperatures ranging from 1,500° to 3,000° Centigrade (2,700° to 5,400°F). The composition is most likely high pressure oxides and silicate minerals high in iron and magnesium. The average composition corresponds to that of peridotite.
2. Outer mantle: The outer mantle begins from 4.8 to 55 kilometers (3 to 35 mi) from the earth's surface. It is 322 kilometers (200 mi) thick and has a specific gravity of 3.3. The Elements nickel, iron, and magnesium combine with SiO_2 to produce mainly olivine, pyroxene, and garnet. This layer is usually warm, plastic, and mobile. Small pockets of molten material are scattered throughout a mass of solid minerals that are near their melting point. The source of internal heat (1,260° to 1,500°C or 2,300° to 2,700°F) is the radioactive decay of uranium, thorium, and potassium. The upper layers of the earth serve as insulation, trapping the heat in the mantle. Hypotheses about internal energy have been made on the basis of several tests, projections, and conclusions. These conclusions were that the rocks having the most rapid production of radioactive heat are located in the outermost portion of the mantle. Further evidence of the character of the mantle as a weak layer near

the outer portions rests in the suggestion that radioactive heat has raised the rock temperature close to melting point in this region. Although the normal melting temperature of the rocks has been reached, the weight of the overlying rocks compresses them to a solid consistency. If and when any of the underlying pressure is released, it results in the eruption of a volcano. There are two zones in the outer mantle that are important in earth dynamics and crustal evolution.

Wonder what's under this continent!

a) Asthenosphere: This zone is of a soft, pliable consistency that is capable of a plastic-like flow. It ranges from 50 to 200 kilometers (30 to 125 mi) below the earth's surface.

b) Lithosphere: This is a rigid layer that includes the crust and the solid portion of the outer mantle above the asthenosphere. (See Figure 8.7)

C. Crust: The crust is the outermost layer of the earth and in comparison to the other layers, it is a thin, rigid shell five to 56 kilometers (3 to 35 mi) thick. As seismic waves pass from the crust to the mantle, an abrupt change in their velocity occurs, indicating a change in the physical properties of the rock layers. A boundary such as this is known as a discontinuity. This particular discontinuity between the crust and mantle is called the Mohorovicic discontinuity (Moho for short), named for the seismologist who discovered the discontinuity in 1909. Because the crust under the continents and oceans differs, they will be discussed separately.

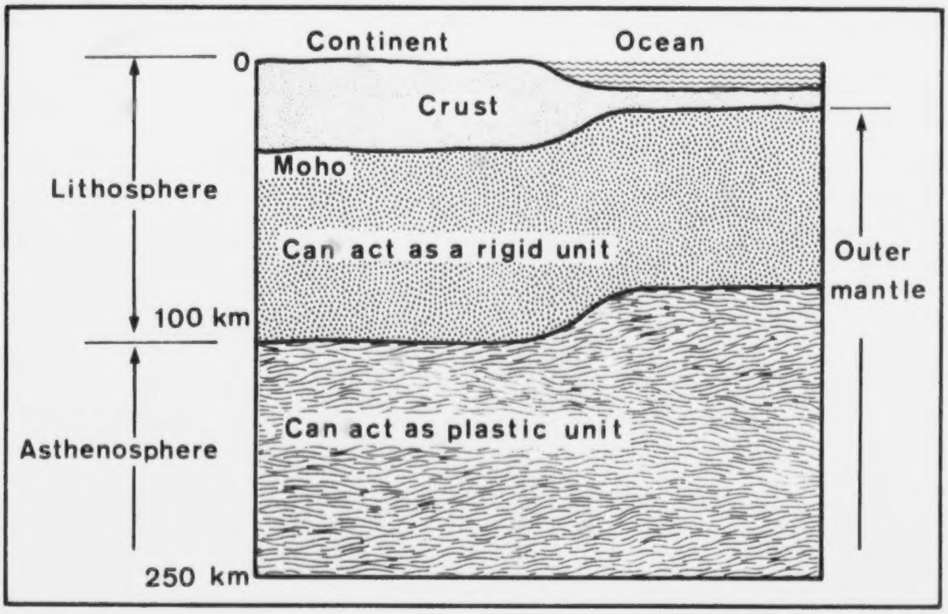


Figure 8.7. This is a cross-section through the crust and a portion of the outer mantle. Note the difference between the crust and the outer mantle, and the lithosphere and asthenosphere.

1. Oceanic crust: The oceanic crust is about 10 kilometers (6 mi) thick and is composed largely of mafic rocks, particularly basalt, that are dark in color and rich in silicon, magnesium, and iron. The specific gravity ranges from 2.9 to 3.1. The rock is more similar in composition to the rock of the mantle than to continental rock. It is assumed that submarine volcanoes were and are responsible for the basaltic lavas on the ocean floor.
2. Continental crust: Unlike the relatively simple and uniform crust of the ocean, the continental crust varies in thickness from less than 24 kilometers (15 mi) to more than 48 kilometers (30 mi). It is composed of felsic rock, predominantly granite, differing from the oceanic crust by being light in color and having more silicon, aluminum, and potassium, and less iron, magnesium, and calcium. It has a specific gravity of 2.7. This crust was probably created in response to the remelting of continental sediments deposited on deep troughs on the continental margins.

SEE ACTIVITY 8.2

3. Isostasy: This is the theory that the crust of the earth floats on the denser, plastic-like mantle in much the same way as a piece of styrofoam floats on water. According to this concept, the denser crustal material, such as that comprising high mountains, sinks deeper into the mantle than the crustal material that is less dense. When any change in the crust occurs, such as erosion (the taking away of material) or deposition (the adding of material), this change will cause an isostatic adjustment. (See Figure 8.8) In other words, if material is removed from a mountain, the mountain will rise because it is lighter. A more active demonstration of isostasy can be seen over parts of North America and Europe where Pleistocene ice sheets covered the ground 25,000 to 50,000 years ago. The weight of the ice sheets forced the crust to sag. When the ice began to melt, isostatic balance was destroyed. In order to reestablish that balance when the ice melted, the crust needed to rise to its near original elevation. Isostatic adjustment could not keep pace with the melting glaciers, so the crust continues to rise today.

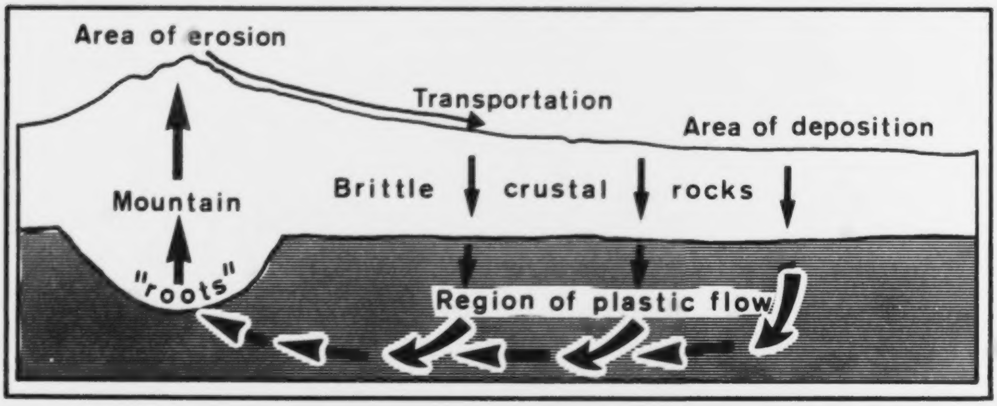


Figure 8.8. An illustration of isostasy in action. Material is worn from the mountain and carried down to land margins. The newly loaded area sinks and the unloaded area rises because the plastic material in the mantle moves from an area of increasing pressure to an area of decreasing pressure.

IV. Summary: In considering the structure of the earth, let us pause to reflect some irony. A person's mere presence in the right place at the wrong time is enough to change a geologic process into a geologic hazard. As the earth trembles, sometimes human creations come crashing down, thus establishing the fact that an earthquake is a geologic hazard. Humanity's inventiveness does not halt once a geologic process has changed into a geologic hazard. Ways have been discovered to use the earthquake waves created by earthquakes to gain insight into the structure of the earth's interior. The character of the various layers is now more thoroughly understood. Fact has replaced fantasy, in many instances, as the discontinuities are realized between the various layers. Finally, there is food for thought. As one topples to the ground from the one hundredth floor of a new "quake-proof" building, s/he can ponder the various routes and movements the earthquake waves are taking at the very same moment her/his descent is being made.

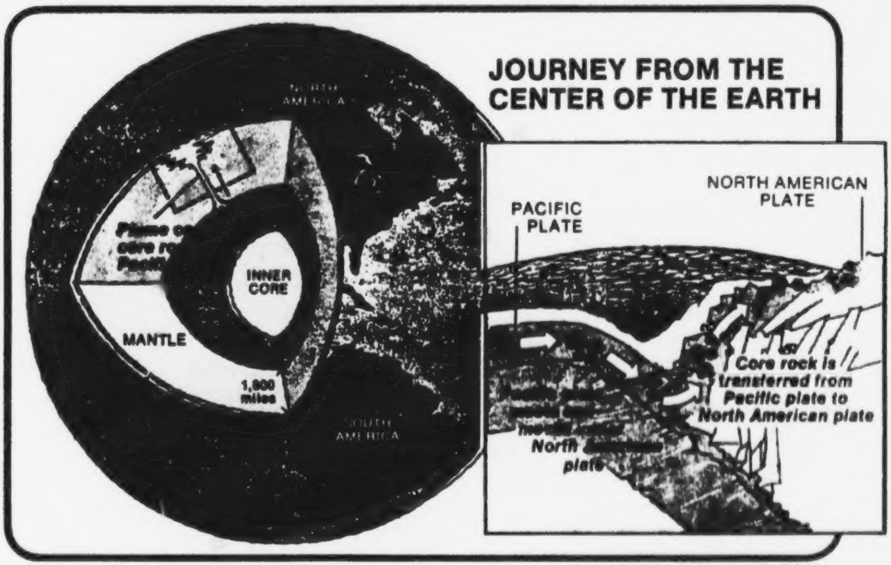
Extra Reading: If you are interested in further reading the article "Core of the Matter," *Newsweek*, LXXXIII, April 22, 1974, follows the chapter.

Chapter 8: Problems and Questions

1. Discuss how seismology is useful in studying the earth's structure. Include in your discussion the influence of the elasticity and density of different materials on the various kinds of earthquake waves.
2. Aside from the supporting evidence provided by meteorites, what qualities do you think iron and nickel have to be the suspected components of the earth's core?
3. The materials in the mantle are way above their melting points, yet they remain nearly solid. Why?
4. If you were given a chunk of basalt and a chunk of granite and were told that they came from the crust, from what part of the crust would you think they probably came. Why?

Core of the Matter

When Cornell University graduate chemist Robert Botto began a course in geology last year, his professor urged him to get acquainted with his subject by examining a collection of rocks stored in the geology laboratory. All the rocks came from meteorites except one, a pockmarked gray stone labeled simply "This is not a meteorite." Intrigued, Botto and his professors decided to analyze the rock and trace its history. Last week, at the annual meeting of the American Geophysical Union, the Cornell scientists announced a startling conclusion: the rock, and a number of others like it, appears to have originated in the earth's core, reaching the surface only after an eons-long journey through 1,800 miles of the solid earth.


JOURNEY FROM THE CENTER OF THE EARTH
NORTH AMERICA
INNER CORE
MANTLE
1,800 miles
SOUTH AMERICA
PACIFIC PLATE
NORTH AMERICAN PLATE
Core rock is transferred from Pacific plate to North American plate
North
plate

Ib Ohlsson

The Oregon trail: One theory of how rock got from the core to the crust

Botto's rock had been dug up in 1892 in Josephine County, Ore., and christened josephinite. It consists predominantly of iron and nickel. Using methods of chemical analysis developed for studying rocks brought back from the moon, the Cornell scientists under the direction of George Morrison found it also contained the mineral garnet—strewn in mazelike patterns between the iron and nickel crystals. No other known rocks contain such a pattern which, according to Cornell geologist John Bird, could only have been caused by a great relaxation in the pressure on the rocks. The single realistic cause of such a relaxation, Bird told the American Geophysical Union, is a journey from the center of the earth.

Seismic studies over the years have shown that the earth's profile consists of three distinct levels. The crust, just 25 miles thick, contains mainly granite and basalt rocks. The mantle, a solid layer of denser rock, stretches down a further 1,800 miles. Beneath the mantle is the core, consisting mainly of iron and nickel. The core is actually divided into two layers—a liquid outside, and a solid center. The Cornell analysis showed the density of josephinite to be similar to that deduced for the outer core, and the scientists concluded that the rocks started out as blobs of molten metal at the boundary between the outer core and the mantle.

To explain the movement of the rocks from there to their resting place in Josephine County, the geologists invoked two relatively recent theories. One, advanced just two years ago, envisions the upward movement of core rock through the solid mantle in hot funnels known as plumes, at a rate of a few yards a year. The other concept is that of plate tectonics, which holds that the continents and the sea bed glide across the underlying solid earth on huge "plates" of rock. The interaction of plumes and moving plates has been suggested as an explanation for the formation of volcanic ranges, such as those in Hawaii: a plate moves across the top of a plume, and the heat from the plume punches a series of holes in the plate.

Route: According to the Cornell scenario, the josephinite was carried through the mantle by a plume—solidifying on the way up—and incorporated into the plate that supports the bottom of the Pacific Ocean. This plate moves continually eastward, until it collides with and drops beneath the North American continental plate at the west coast of the U.S. At this point of collision, the Cornell scientists suggest, the josephinite rocks were detached from the Pacific plate and incorporated into the North American one, ending up in Oregon.

The interpretation is sure to spark controversy among geologists. Nevertheless, Bird noted last week, "If it's wrong, somebody is going to have to come up with a better explanation." If further studies prove the scenario to be correct, then the josephinite rocks will provide geologists with important new clues on the internal make-up and origin of the planet earth.

Fortunately, there is no shortage of josephinite rocks to study. They are already on display in many major museums and private rock collections. Furthermore, the major deposit of the rocks in Oregon lies beneath land owned by a prospector who sells samples. Before last week's announcement, the going price for a putative piece of the earth's core was $7 an ounce.

Source: Newsweek,
LXXXIII, (April
22, 1974),
pp. 77,78.

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Unit IV: Internal Processes

CHAPTER 9: Plate Tectonics

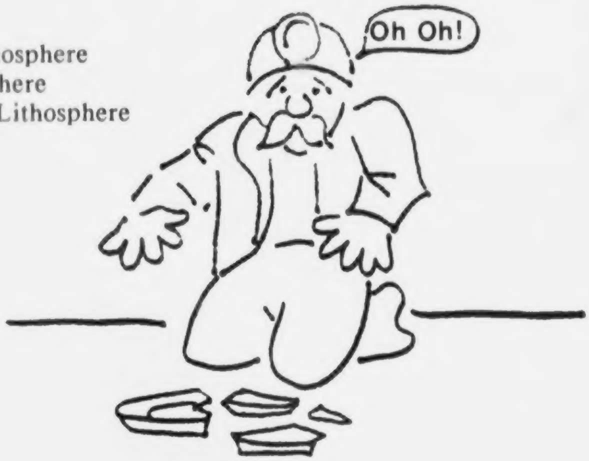
I. Introduction

II. Historical Background
  A. 4th Century
  B. 15th Century
  C. 17th Century
  D. 18th Century
  E. Early 20th Century
  F. Mid 20th Century

III. Development of Present Theory
  A. Early Evidence
    1. Correlation
      a) Physical
      b) Biological
    2. Climatic Evidence
  B. More Recent Evidence
    1. Magnetism
      a) Paleomagnetism
      b) Magnetic Reversals
    2. Earthquake and Volcano Patterns
    3. Ocean Basin Typography
    4. Radioactive Dating

IV. The Theory of Plate Tectonics
  A. Geography of the Plates
  B. Plate Boundaries and Movement
    1. Divergent Plate Boundaries
      a) Sea Floor Development
      b) Ridge Development
      c) Magnetic Evidence
      d) Spreading Rates
    2. Convergent Plate Boundaries
      a) Continental Against Oceanic Lithosphere
      b) Oceanic Against Oceanic Lithosphere
      c) Continental Against Continental Lithosphere
    3. Lateral-motion Plate Boundaries
  C. Mechanism for Movement
  D. Past Plate Movement
    1. Physical Developments
    2. Biological Developments
  E. Future Plate Movement
    1. Physical Developments
    2. Biological Developments

V. Consequences of Plate Movement
  A. Earthquakes
  B. Volcanoes



        1. Subduction Zones
        2. Divergent Zones
        3. Hot Spots
    C. Mountain Building
    D. Mineral Resources
    E. Energy Sources

VI. Summary

Related Activities

Vocabulary

Use given data to reach conclusions about sea-floor spreading.

Work a puzzle using plate tectonics vocabulary terms.

Plot plate boundaries on a world map.

Problems and questions

Plate Tectonics Geo Facts

Africa and Eurasia are moving together to destroy the Mediterranean Sea, which will be replaced by a chain of mountains. The island of Cyprus is just the beginning of this chain.

If the walls of the trenches could be seen, some could compare in size to seven Grand Canyons piled on top of each other. They would extend from New York to Kansas City.

The oldest oceanic rock is less than 180 million years old compared to the oldest continental rock which is 3.8 billion years old.

The only reason Europe and North America have oil and gas fields is these parts of the world were once much closer to the equator.

One hypothesis concerning the legendary Atlantis is that it was destroyed by plate movement and subsequent earthquake and volcanic activity.

The South Pole and its ice cap were once located where the Sahara Desert now sits. Furthermore, sahara means desert.

Chapter 9: Word List

Drifting Definitions

Asthenosphere
Continental drift
Convection cell
Convergent plate boundary
Divergent plate boundary
Fault
Gondwanaland
Hot spot
Island arc
Lateral-motion plate boundary
Laurasia
Lithosphere
Mid-oceanic ridge
Paleomagnetism
Pangaea
Plate
Plate tectonics
Plume
Ridge
Rift
Sea-floor spreading
Subduction
Supercontinent
Tectonic
Transform Fault
Trench

Straight Terms

Amphibian
Converge
Correlate
Diverge
Fluctuation
Extinction
Meteorologist
Polarity
Prevalent
Remnant
Reptile
Static
Striated
Symmetrical

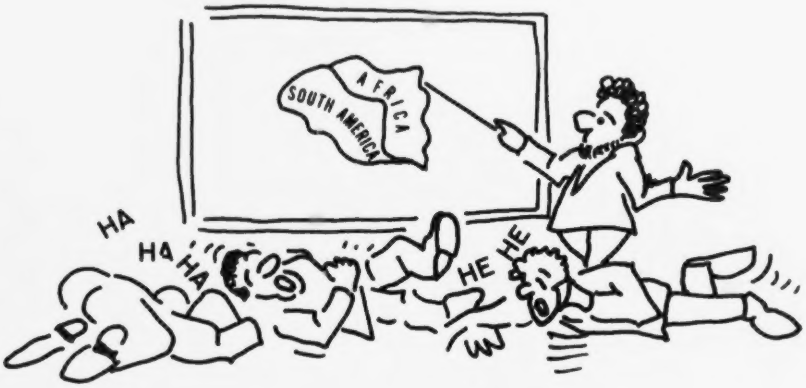
UNIT IV: INTERNAL PROCESSES

Chapter 9: Plate Tectonics

I. Introduction:

Bulletin--India Crashes into Asia Creating Himalayas

This statement seems wild, and for hundreds of years, anyone who considered it possible was also regarded as a little bit wild. It was part of an entire idea originally known as the theory of continental drift. This idea stated that after having been united into one supercontinent, the land broke into separate continents that drifted around on the surface of the earth. This chapter will study the further development of the theory of continental drift into the theory of plate tectonics. (Tectonic refers to the deformation of the earth's crust.) The plate tectonic theory describes the presence in the lithosphere of 11 or 12 major plates (large pieces of the earth's crust) and a dozen smaller ones that move relative to each other. The hows, whys, and wherefores of plate tectonics will be considered as you are introduced to one of the "hottest" topics in modern geology.



II. Historical Background: The idea of the continents moving about on the earth's surface is not really a new one. We can trace the origins back many centuries.
  A. 4th Century B.C.: Aristotle ponders over discoveries of marine animals on mountain tops.
  B. 15th Century: Leonard de Vinci writes, "Above the plains of Italy where flocks of birds are flying today, fishes were once moving in large shoals."
  C. 17th Century: Sir Francis Bacon noted the correspondence between the shapes of the eastern shoreline of South America and the western shoreline of Africa.

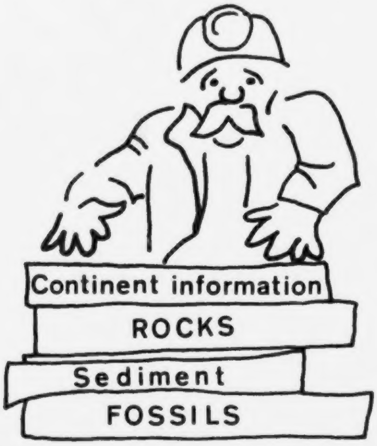
D. 18th Century: Benjamin Franklin, after finding oyster shells on mountain tops writes "The surface of the globe would be capable of being broken and disordered by violent movements of the fluids on which it rests."

E. Early 20th Century: Meteorologist Alfred Wegner was first credited with the theory of continental drift. His discoveries and conclusions were published in 1912. Wegner was unable to gain much support for his theory because many of his conclusions could be explained without continental drift and he could not explain the cause of the movement.

F. Mid 20th Century: In the 1950's and 1960's, there was wider acceptance of the possibility of continental drift. During this time, new studies were being conducted into such fields as oceanography, paleomagnetism, and the dating of rocks on both continents and on the ocean bottom.

III. The Theory of Plate Tectonics: To anyone once observing a world map, the way the shorelines of Africa and South America fit together seemed interesting. To go beyond that mere step of the observation that the shorelines may have fit together, and to form a unifying theory of continental drift took many scientists years of compiling evidence.

A. Early Evidence: Before the birth of sophisticated gadgets, scientists depended upon a great deal of observation. Through much scientific investigation, a pile of evidence began to accumulate in support of continental drift.



1. Correlation: A correlation is a mutual relationship, such as a specific fossil in two different locations but in identical rock. This was used as some of the first evidence to support continental drift.

   a) Physical: Of course, one of the first lines of physical evidence came when rough fits could be made of the continental margins. The matching rock types and relative ages from the margin of one continent to another had to more than coincidental. (See Figure 9.1) Not only did the mountain structures in the Appalachians correlate up through Nova Scotia and Newfoundland and line up with those in the British Isles and Norway, but also they were of the same geologic age.

   b) Biological: The *Glossopteris* fossil leaf (with which you are no doubt familiar) provides a bit of evidence for continental drift. Its fossil remains are found in Africa, Australia, India, Madagascar, South America, and Antarctica. These continents would have had to be joined for such an occurrence, because *Glossopteris* was diversified enough to spread. In addition, a Permian reptile called *Mesosaurus* is found both in South

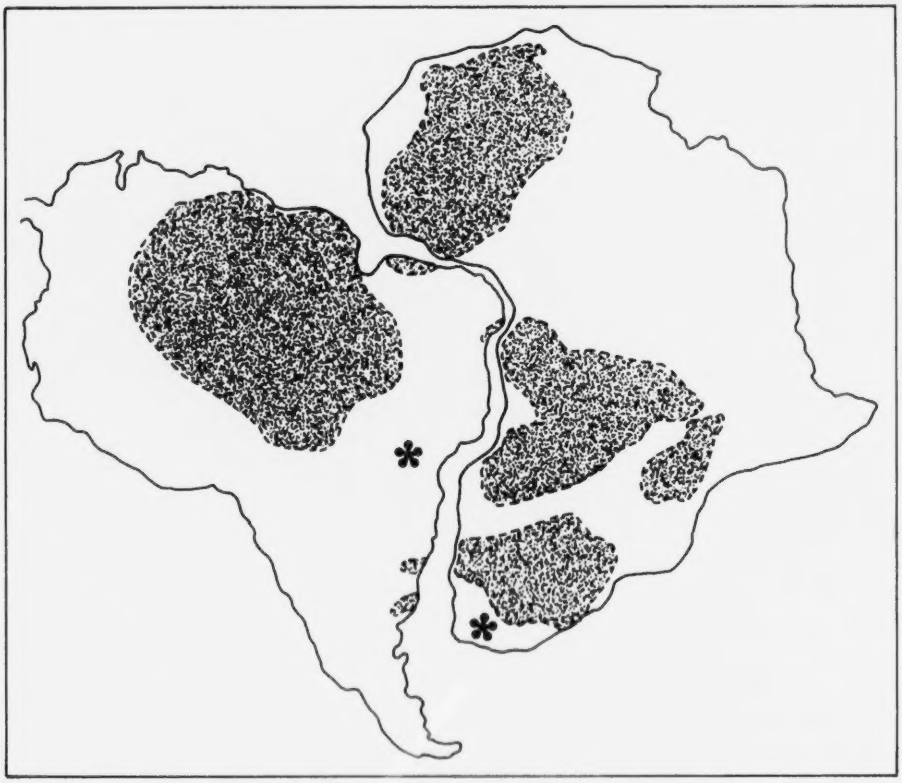
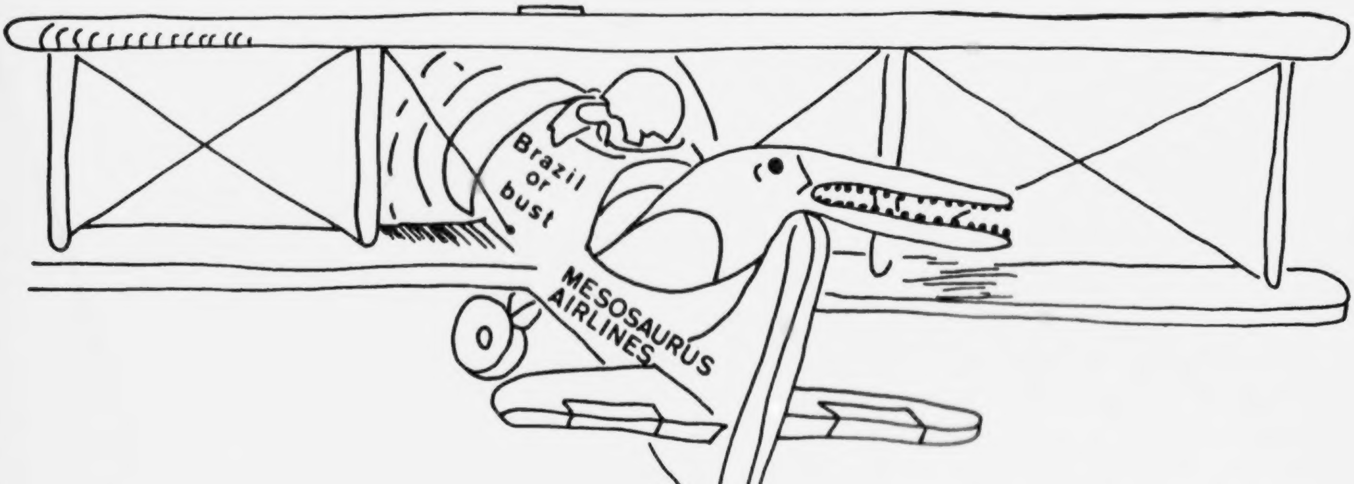


Figure 9.1. The map of Africa and South America represents the geologic fit of the two countries. The shaded areas are locations of rock that are of the same age and type. The stars indicate some localities where *Mesosaurus* has been found.

America and Africa, in similar rock beds. Aside from *Mesosaurus* flying the Permian 747 from one continent to another, the only possibility for this correlation is that the two countries were once joined. Although *Mesosaurus* was a swimmer, it did so in fresh-water; therefore, it is unlikely that the reptile could swim across the salt-water ocean.



2. Climatic Evidence: There is evidence of late Pennsylvanian or early Permian glaciation in South Africa, South America, India, and Australia. This indicates that those regions experienced climates markedly different from those of present day. Evidence of the presence of glaciers included glacial boulders lying on bedrock floors, polished and striated as only glaciers can produce. In addition, layers of glacial sedimentary rock called tillites were found in numerous locations. Later, it was discovered that Antarctica had also been glaciated in the same time period. (See Figure 9.2) It was concluded that glaciers could not have existed on these continents at that time if they occupied their present-day positions; this would have put major glaciers in India 20° north of the equator, similar glaciers in Brazil 10° south of the equator, and another glacier in Africa 20° south of the equator. During the time that those ice sheets lay in equatorial regions, Europe and North America were warm and humid, and they supported tremendous coal swamps with plants that differed from those in the Southern Hemisphere. In addition to the plants, great numbers of large insects, amphibians, and reptiles existed in this warm climate. Clearly this could not have happened unless the Southern Hemisphere continents were grouped together, probably around the South Pole, while Europe and North America were located nearer the equator.

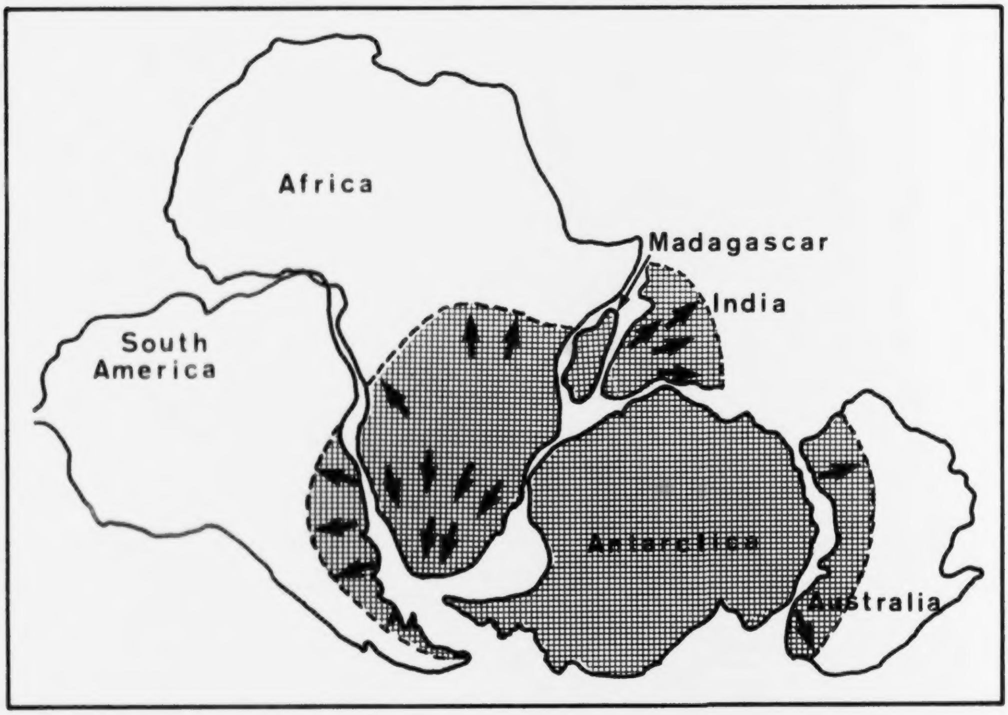
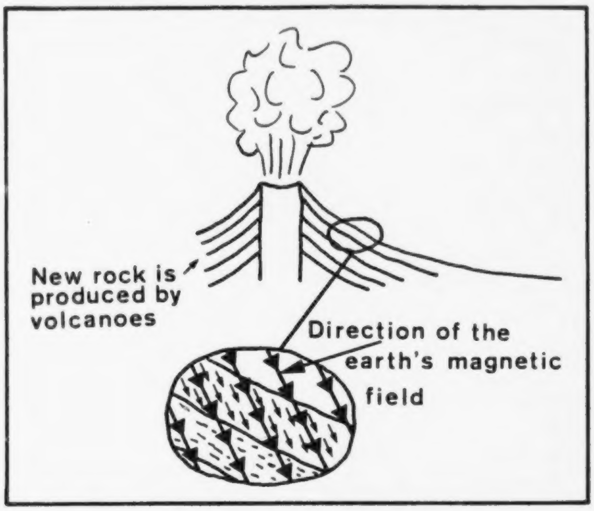


Figure 9.2. In this reconstruction of Gondwanaland, the regions affected by glaciation are indicated by the shaded areas. The arrows show the directions of the ice movement.

B. More Recent Evidence: With newer devices, more evidence came into light which would have made Wegner smile.

1. Magnetism: When lava cools to a certain temperature, iron minerals within the liquid become magnetic and align themselves just like compass needles with the lines of force of the earth's magnetic field. This orientation can easily be determined by an instrument that measures magnetism called a magnetometer. The crystals within the rock become a permanent record of the orientation of the rock with respect to the earth's magnetic field at the time the lava solidified. (See Figure 9.3)
    a) Paleomagnetism: This record is known as remnant magnetism or paleomagnetism. Some scientists learned that these "fossil compasses" indicated that the earth's polarity had changed positions and had actually reversed position in the past--the north and south magnetic poles had repeatedly changed places. Another line of evidence seemed to indicate that the magnetic north had migrated from a Precambrian location in southwestern United States, westward, out into the Pacific Ocean. It seemingly continued to wander various places. Polar wandering was puzzling. The problem was solved when "polar wandering paths" were determined for rocks of other continents. Scientists were amazed to learn that each continent had a distinctive "polar wandering path" that varied for each continent. There was only one explanation--the poles must have been nearly static, for if they had moved, the rocks of each continent would preserve a nearly identical wandering path. The record of wandering, then, was the record of wandering continents and not poles. This was the first quantitative data supporting continental drift.
    b) Magnetic Stripes: In the early 1960's, it was discovered that there was a zebra-like striped pattern of bands that had alternately been strong and weak remnant magnetism on both sides of the oceanic ridges. The strips were zones of alternating north and south polarity marking the reversals in polarity through the years. As the story is pieced together, it seems that as the new sea floor forms along the oceanic ridges, it acquires the remnant magnetism of the then prevalent polarity (either north or south). The sea floor moves away from both sides of the ridge as equally broad, similarly magnetized strips of rock or sea floor. Thus, the strips are symmetrical on each side of the mid-oceanic ridges. They record each change of polarity and form the "growth lines" of ocean basins.

Figure 9.3. Illustrates how, as volcanic rock cools, it becomes magnetized in the direction of the prevailing magnetic field.


New rock is produced by volcanoes
Direction of the earth's magnetic field

2. Earthquake and Volcano Patterns: With the aid of super-sensitive seismographs, scientists began plotting the locations of every single earthquake. A pattern became obvious after a time showing that about 90 percent of all earthquakes occur along a few narrow belts which turned out to be plate boundaries. Volcano patterns also seemed to follow the plate boundaries indicating unstable areas.
3. Ocean Basin Typography: In the late 1950's, there was a massive effort to map the world's ocean floors in preparation for possible undersea warfare. New deep-ocean sounding devices revealed the ocean floor, not as a flat plain as previously believed, but rather as an area of flat-topped mountains, and jagged ridges. In fact, the ridges in the Atlantic were found to parallel the continental margins on either side. Now the matching shorelines could not be dismissed as a coincidence.

4. Radioactive dating: (rocks not people) This breakthrough enabled geologists to determine the age of rocks in actual years. It was through this technique that scientists were able to prove that the ocean floor was much younger than the continental cores (shields) and that ocean rock near rift zones was younger than the ocean rock on either side of the rift.

SOUTH AMERICA
AFRICA

IV. Present plate tectonic theory: Continental drift was initially proposed as a process taking place by continents "plowing" through the sea floor. It was difficult to accept because continents are relatively weak, easily crumpled rock bodies that are not flexible enough to force their way through a rigid ocean floor. Now, we no longer think of the continents moving in that manner. Rather, we see them riding as passengers on thick plates of lithosphere that are composed of the crust and part of the outer mantle. (See Figure 9.4) Various discoveries of evidence have resulted in the plate tectonics theory, the modern explanation of continental drift.

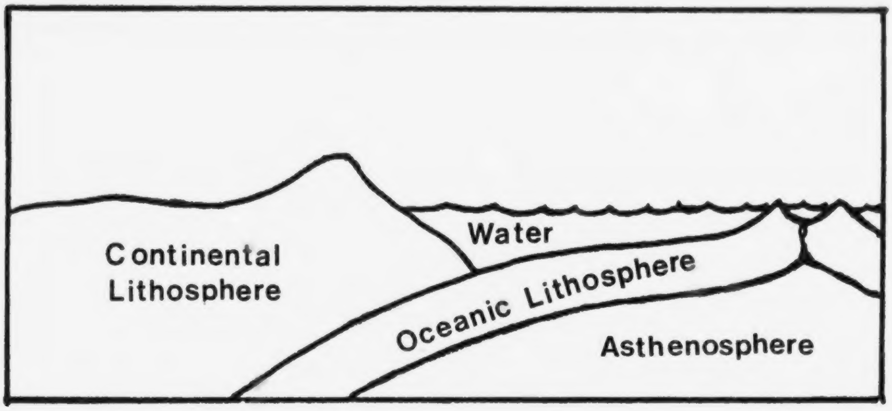


Figure 9.4. A generalized view of plates and plate boundaries.

A. Geography of the plates: The lithosphere is divided into more than 12 rigid crustal blocks shaped like inverted soup bowls. They are moved around by internal forces that add to the plates in some regions and destroy them in others. They cover the earth's surface and do not always parallel boundaries of the continents. The plates vary in size. Some are huge and carry two continents. North and South America are thought to be on a single plate. (See Figure 9.5) Other plates are small, such as the Aegean plate which carries a part of Greece, the Aegean Sea floor, and a small segment of western Turkey. Both the Pacific and Atlantic Oceans are shared by a number of plates. Most are a mixture of continental and oceanic crust, but there are several composed strictly of oceanic crust. They range in thickness, with the oceanic portions being about 80 kilometers (50 mi) thick and the continental portions being 100 to 150 kilometers (62 to 93 mi) thick. The plates are in constant motion, and the average plate movement is about 5 centimeters (2 in) a year.

B. Plate boundaries and movement: The plates have three different kinds of boundaries. The cardinal rule of plate tectonics is that very little change occurs to crustal rock in the middle of the plates. Nearly all changes take place near the edges, and the presence of plate boundaries helps explain many geologic occurrences, such as earthquakes, volcanoes, and mountain building.

   1. Divergent plate boundaries: These are boundaries in which the plates separate or move away from each other. A gap or rift forms between them, and the intervening space is immediately filled with magma rising from the mantle up through the rift to form mafic igneous rock. (See Figure 9.6) This can occur along ocean ridges where sea-floor spreading is occurring.

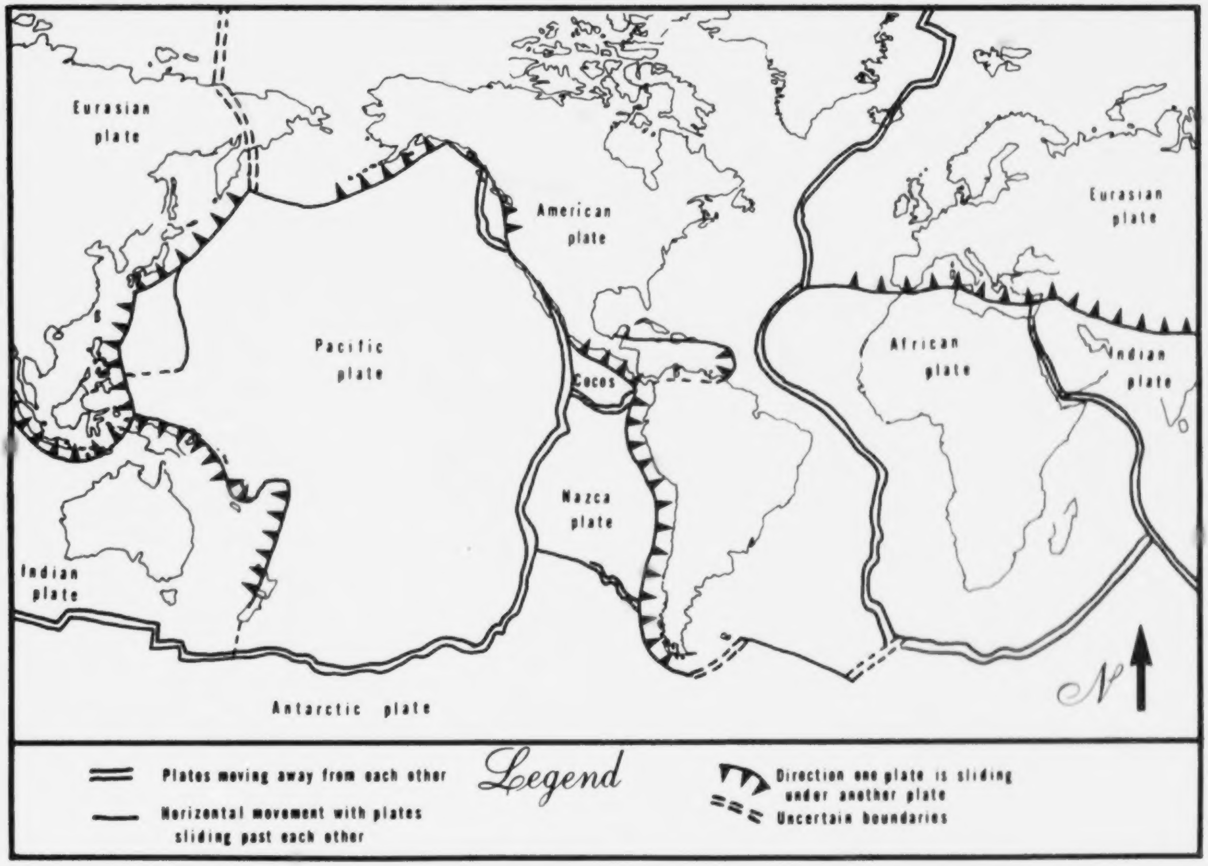

Eurasian plate
American plate
Eurasian plate
Pacific plate
Cocos
African plate
Indian plate
Nazca plate
Indian plate
Antarctic plate
N
Legend
Plates moving away from each other
Horizontal movement with plates sliding past each other
Direction one plate is sliding under another plate
Uncertain boundaries

Figure 9.5. Major plates of the earth and their boundaries.

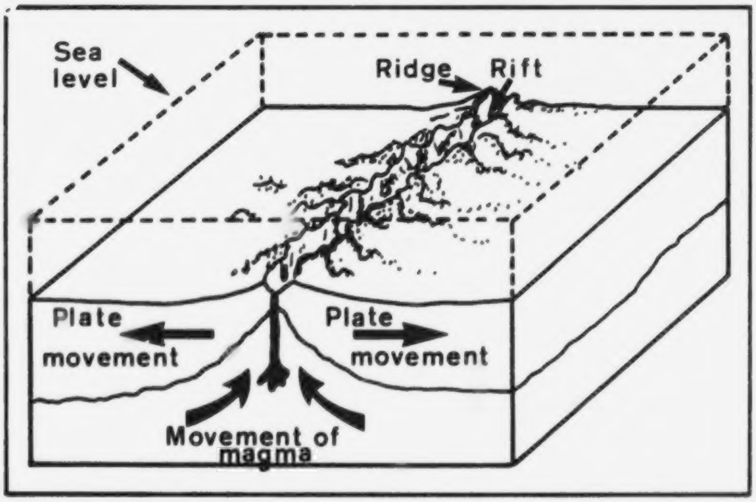

Sea level
Ridge
Rift
Plate movement
Plate movement
Movement of magma

Figure 9.6. Divergent plate boundaries are those that spread apart as magma rises between the plates.

a) Sea-floor development: Sea-floor spreading is the process whereby magma wells up in the rift formed by divergent plates, hardens, welds itself to the plates on either side, and moves off across the ocean floor. It is believed that oceanic crust present today was formed by this process. The amount of material added to each plate is equal on each side, so the divergent zone remains in the middle, and spreading is symmetrical. The youngest rocks are in the middle and get older as they extend away from the rift. (See Figure 9.7) An example can be seen in the Atlantic Ocean. The beauty of discovering this process is that scientists now have an explanation for the growth in plates.

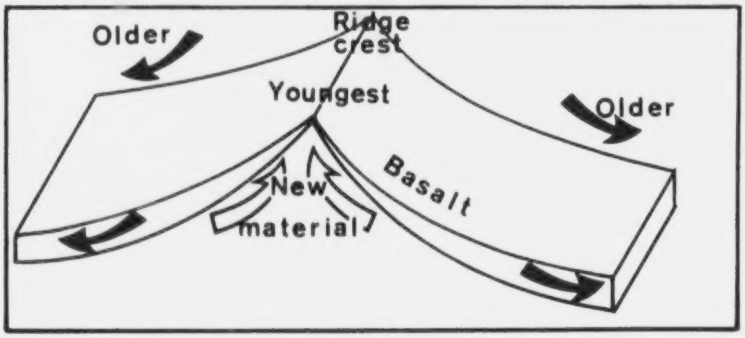


Figure 9.7. Illustrates the age of rocks composing the sea floor near two divergent plate boundaries.

b) Ridge development: The magma that reaches the earth's surface is obviously hot. It takes a long time for the heat to be released because of the thickness of the plates. Recall that most objects expand when heated and contract when cooled. Because heat is temporarily retained by the rock near the rift, the divergent zone is expanded and therefore elevated above the surrounding lower, cooler area. If the rift is on a continent, it appears as a great area uplifted like a large plateau. This can be seen in the upland plains of Kenya and Tanzania, along the East African Rift Valley. If the rift is on the ocean floor, crests or ridges along the rift are formed. (See Figure 9.6) It is along these ridges that shallow earthquakes occur. Crests found in the middle of the ocean are called mid-oceanic ridges. If the sea-floor spreading has been slow, as has been the Mid-Atlantic Ridge of the Atlantic Ocean, the topography is rough with the rift zone obvious as a valley on the crest of a ridge, or a long submarine mountain. If the spreading is more rapid, as has been the Pacific-Antarctic Rise of the Pacific Ocean, the topography is smoother, with no rift valley obvious.

c) Spreading rates: The rate of sea-floor spreading for the Mid-Atlantic Ridge has been calculated to average about six centimeters (2 in) per year. At that rate, North and South America would have traveled the 2,400 kilometers (1,500 mi) westward from the mid-oceanic ridge in about 100 million years, while Europe and Africa would have traveled an equivalent distance eastward during the same time period. In other terms, the North American plate is moving westward measured by the length of one's body in the timespan of one life.

SEE ACTIVITY 9.1

2. Convergent plate boundaries: This is the type of boundary in which the plates run into each other. (See Figure 9.8) It seems logical that to keep the earth in balance, since plates are created at divergent plate boundaries, they must be destroyed elsewhere to maintain a balance. This destruction takes place at the convergent plate boundaries. One of three situations may exist.

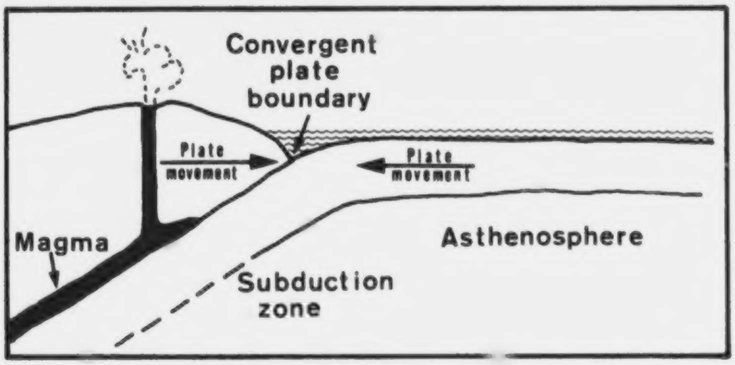

Convergent plate boundary
Plate movement
Plate movement
Magma
Asthenosphere
Subduction zone

Figure 9.8. When two plates collide, the boundary is called a convergent plate boundary.

a) Continental against oceanic lithosphere: When a continental plate meets an oceanic plate, because the oceanic plate is denser than the continental plate, the oceanic plate dips steeply and descends into the mantle, or asthenosphere. When the oceanic plate reaches a deep enough depth, it is remelted in the underlying asthenosphere (recycling at its finest). This entire process is known as subduction. (See Figure 9.9) Since it appears continental sediment is also remelted, the "new" rock tends to be lighter in color and less dense than oceanic rock. As the subduction occurs beneath the continental mass, the lava forms mountains or plateaus on the continent. Examples of this process in action include the Cascades of the Pacific Northwest and the Andes of South America. (Wow, I bet that's where the name andesite came from!)

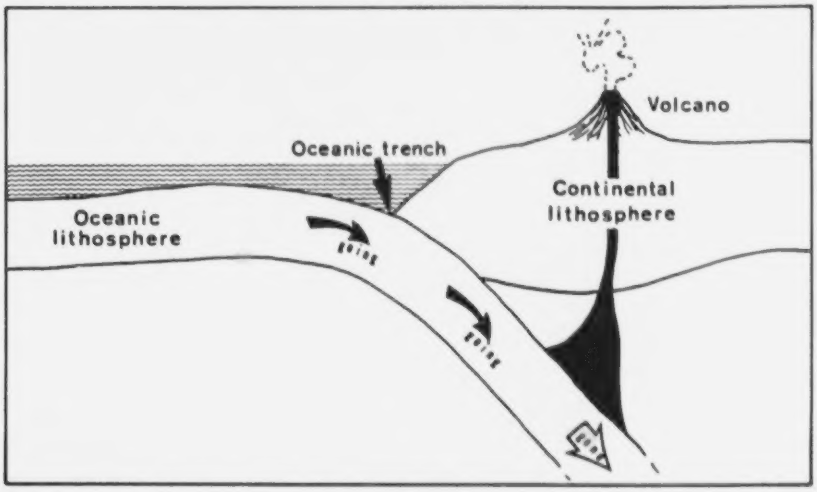

Volcano
Oceanic trench
Continental lithosphere
Oceanic lithosphere
going
going
gone

Figure 9.9. The collision of an oceanic and continental plate. Friction of the plates causes localized melting and volcanoes.

Trenches (steep-sided, long depressions in the ocean floor) are surface expressions of subduction. As the oceanic plate bends down to slide under the continental plate, oceanic trenches form along the region of meeting.

b) Oceanic and oceanic lithosphere: When two oceanic plates meet, the faster moving will subduct beneath the other. Subducted, Again! As with the continental/oceanic boundary, a trench will be formed at the subduction zone. Some of the deepest parts of the ocean occur in oceanic trenches, with the deepest being at the Marianas Trench in the western Pacific, where the water depth is over 11 kilometers (7 mi) deep. Since oceanic plates have little continental sediment, the new volcanic rocks that are formed after remelting of the diving plate are dense mafic lavas that usually form a series of volcanic islands called island arcs. The islands of Japan in the Pacific and the Aleutians of Alaska are such island arcs.

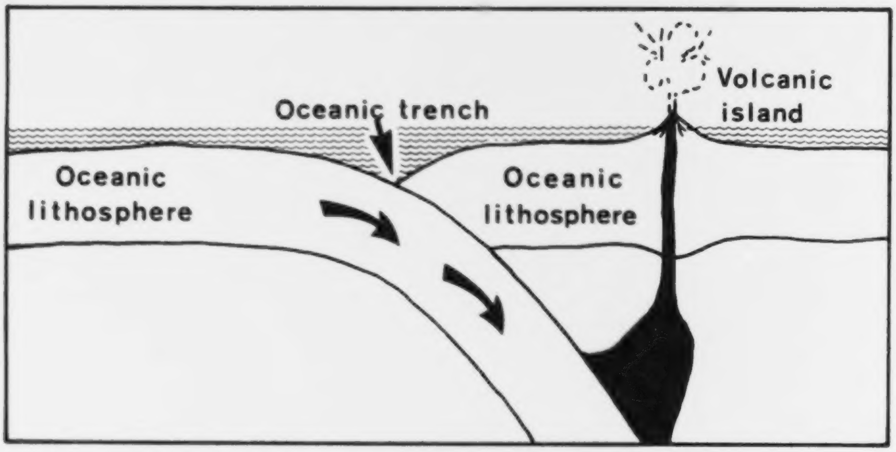


Figure 9.10. As two oceanic plates meet, one dives under the other. The resulting friction causes localized melting.

c) Continental against continental lithosphere: Because these plates are composed of much less dense material, it is difficult for either of them to be forced down into the mantle. Instead, when they meet, they butt directly into each other to throw up huge mountain ranges such as the Himalayas. (See Figure 9.11)

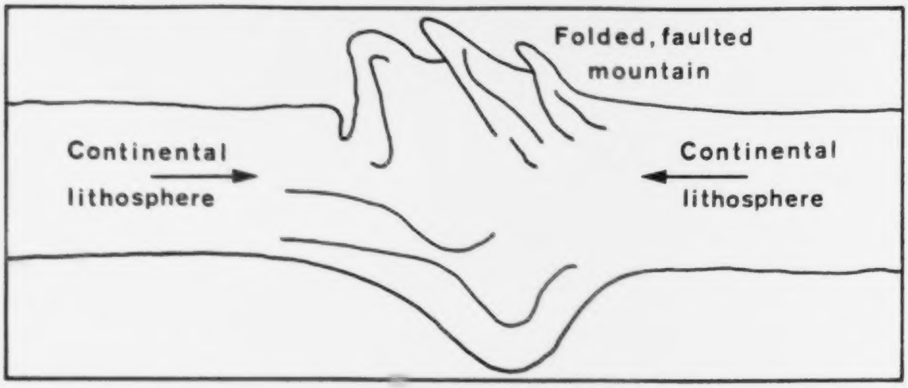


Figure 9.11. When two continental plates collide, the result is a crumpled mountain range and a new tourist trap.

3. Lateral-motion or transform fault plate boundaries: A fault is a crack in the earth's crust along which two blocks of earth move past each other. There are several different possible fault movements. The type we are interested in now is the lateral-motion fault. This third type of plate movement simply involves two plates sliding past each other horizontally, and with the movement, there is frequently seismic activity. There is neither loss nor gain of area. (See Figure 9.12) The most-studied lateral-motion plate boundary is the San Andreas fault zone in California. (Those of you who pursue intellectual movies will recognize this name from *Superman the Movie*. It was movement along this fault that was initiated by the bad guy and halted by our hero, Superman.) Lateral-motion faults are of great length, usually several hundred to a thousand or more kilometers in length. They are usually paralleled by ridges and troughs.

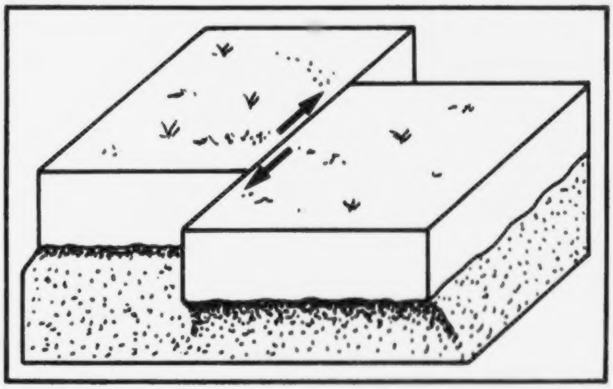
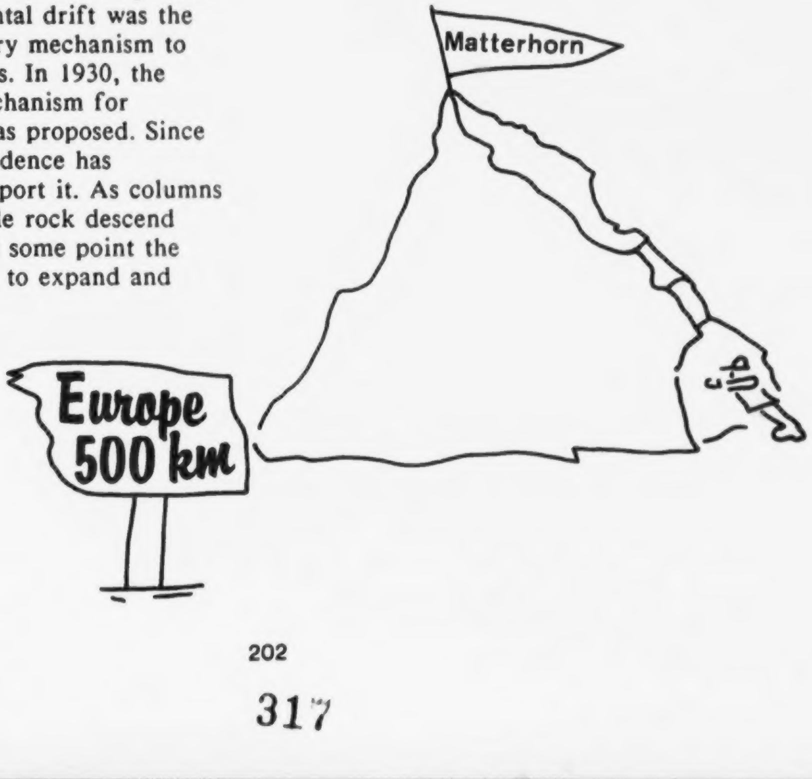


Figure 9.12. An illustration of a lateral-motion plate boundary. The arrows show the direction of plate movement.

C. Mechanism for movement: The greatest stumbling block encountered by those supporting continental drift was the lack of a satisfactory mechanism to move the continents. In 1930, the convection cell mechanism for continental drift was proposed. Since that time, more evidence has accumulated to support it. As columns of hot, dense mantle rock descend they are heated. At some point the molten rock begins to expand and rise. Following that, the magma spreads out laterally near the bottom of the lithosphere, cools, becomes more dense, and sinks. The pattern of



descending magma that reheats, expands, and rises again is known as a convection cell. (See Figure 9.13) The plates rest on the asthenosphere and move in response to the movement of the convection cells. Also within convection cells are rising columns of magma called plumes or diapirs. Because there are believed to be several convection cells within the mantle, there are several plumes. Most active plumes are not far from ocean rifts, such as Iceland, the Azores, and the Canary Islands.

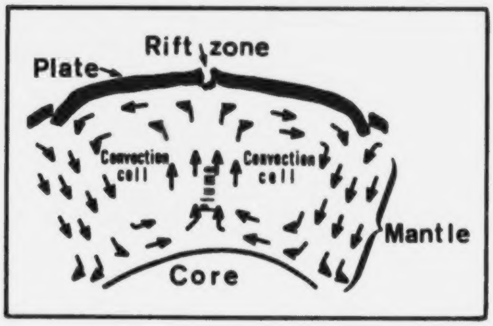


Figure 9.13. This is a diagram of two convection cells within the mantle. The arrows in the mantle show the direction the magma is flowing.

D. Past plate movement: Although little is known about the original crust of the earth as to composition and time of formation, there seem to have been granitic or continental rocks at least as long ago as 3.8 billion years. Probably, the mechanisms of continental drift were also in operation at a very early time.

1. Physical developments: It is difficult to piece together the history of past plate movements. Part of the problem is finding old plates because so many have been destroyed, as a result also destroying any past records. However, by analyzing the radioactive mineral content of the rocks involved, the ages of Precambrian mountain building episodes can be determined, indicating when crustal materials were being brought together to form folded mountains.

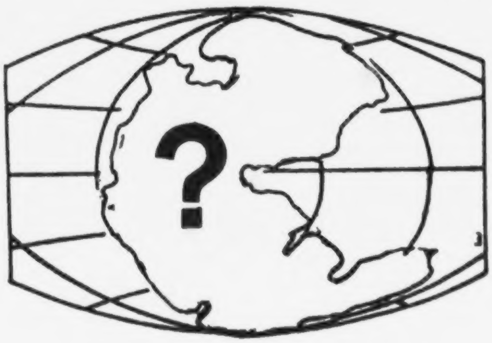
   The following is a generalized view of past continental movement and the resulting landform movement.

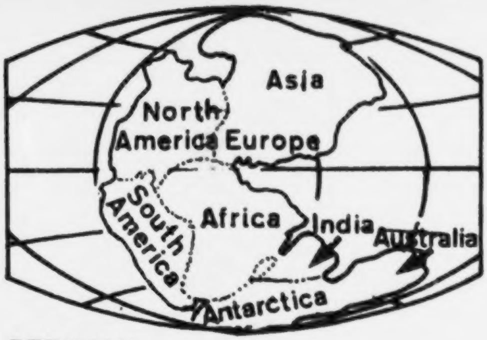
2.8 billion years ago--all continental crust on the earth comes together in one super continent and then breaks apart.

1.9 billion years ago--Another supercontinent forms and breaks up.

1.1 billion years ago--And another.

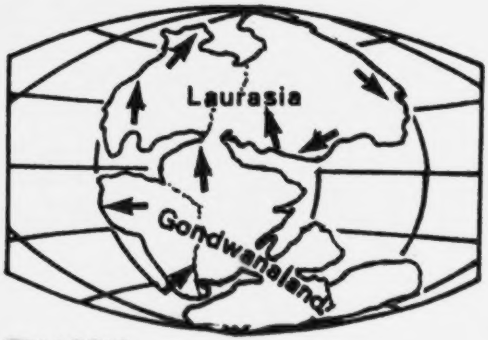
700 million years ago--And another.




Asia
North America
Europe
South America
Africa
India
Australia
Antarctica

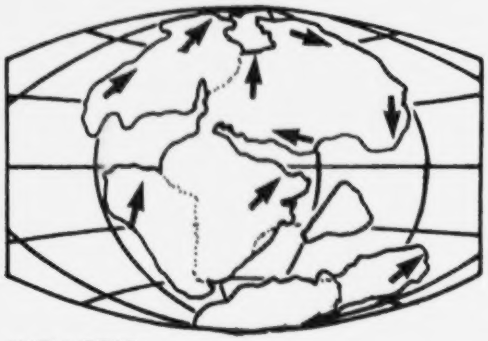
PERMIAN

270 million years ago--Pangaea is formed, the last great supercontinent. The ancient Appalachians created.


Laurasia
Gondwanaland

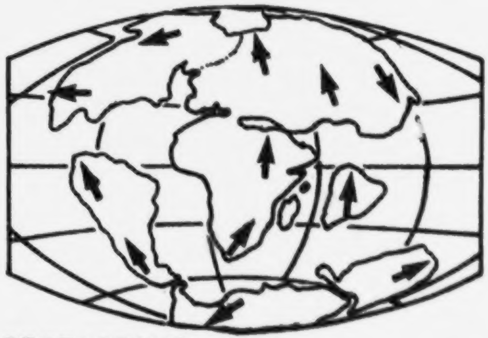
TRIASSIC

205 million years ago--Pangaea has split into a northern group of continents called Laurasia and a southern group called Gondwanaland.



JURASSIC

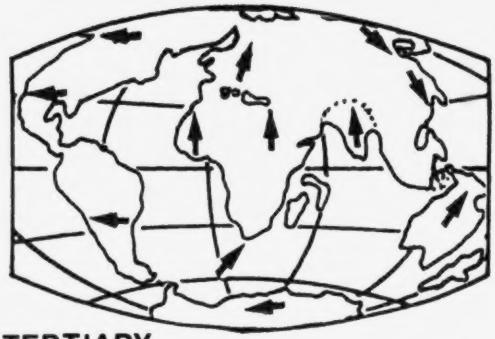
140 million years ago--Gondwanaland breaks up, India is set free to head for Asia. Antarctica and Australia begin to split from Africa-South America



CRETACEOUS

135 million years ago--North Atlantic and Indian Oceans have increased in size. South America has started to split from Africa. Ancient Rocky Mnts. begin to form in North America.

50 million years ago--India crashes into Asia. Antarctica and Australia are split by a rift.
24 million years ago--Africa and Asia welded together in the Middle East. Alps formed as Africa and Europe collide.
15 million years ago- Spain and Africa close, Mediterranean Sea formed.
3 million years ago--North and South America are joined. And It Just Keeps Going!



TERTIARY

2. Biological developments: Upon the formation of Pangaea, changes in climate occurred that thereby affected plant and animal life. The larger continents would have caused greater monsoons than those today. As a result, offshore winds brought up more cold, nutrient-rich water. Conversely, onshore winds brought in warm water that was poorer in nutrients. All of these weather changes caused great seasonal fluctuations in the near-shore food supply, and they increased competition among near-shore sea animals for scarce food. The climate had strongly expressed seasons, with colder winters and warmer summers. All of those factors placed stress on living organisms and hampered their survival. Compounding this, species of animals that were formerly isolated were brought into contact with each other as their previously isolated continent-island homes joined one another. This led to competition among species for food sources and living space. It exposed them to diseases that they had not previously encountered and that they may have lacked natural immunities to or defenses against. The result of all this was that the Permian was a time of great extinctions. Many specialized animals, such as trilobytes and brachiopods, that could not adapt to the changes died out. Many biologically simpler, less specialized animals, such as insects, survived and may have evolved into new groups.

E. Future plate movement: Now that you know from where you have come, consider where you are going.
   1. Physical developments: North and South America, on a single large plate, will continue drifting westward to eventually collide with Asia (finally a merger between the Americans and Chinese, whatever our beliefs). Australia and New Guinea will continue drifting northward toward the islands southeast of Asia and Asia itself. India will continue to slide under Asia; thus, the Himalayas will remain high and tectonically active. Africa will persist in its movement northward and westward. This may cause mountains to rise and block the Strait of Gibraltar, thus blocking access to the Atlantic Ocean. With this, the Mediterranean Sea could evaporate, and its basin would become an extensive salt flat, similar to Death Valley, but much larger and thousands of meters below sea level. Ultimately, all of the major land masses will once more collide to form a new supercontinent.

L. A. city limits
Seattle ½ mile

2. Biological developments: The greatest extinction of animals and plants will result after the major land masses collide to form a new supercontinent. Generally, the more highly evolved animals live on the larger land-masses, such as Europe-Asia and North America. These animals will more likely survive, although not all of them will. Animals that live on smaller, especially isolated land masses are less highly evolved and will be much less likely to survive. Presumably, larger land areas have more kinds of animals. This leads to greater competition among species and, consequently, a more highly evolved series of animals. Australia's animals, such as the defenseless koala bear, will have the greatest number of extinctions. These will be followed, in order, by the animals of South America and then Africa.

V. Consequences of plate movement: "And what," you ask yourself, "does this have to do with me?" Man is an animal that has endless questions about endless topics. The beauty of plate tectonics is that through one theory, many questions can be answered, and many seemingly separate phenomena can be accounted for.

A. Earthquakes: Earthquakes occur when rock under stress breaks. What causes rock in the earth's crust to be under stress? The major cause is that under certain conditions crustal plates "lock up" and stop moving. Since the driving force continues, at some point in time, the rocks will break loose causing an earthquake. Large earthquakes are most common near subduction zones such as along the western South American coast and near Japan; and along lateral motion (transform) faults such as the San Andreas Fault Zone in southern California. Earthquakes near divergent boundaries are usually small and associated with volcanic activity.

B. Volcanoes: As noted in the section on plate boundaries in this chapter, lava is often produced at plate boundaries. Volcanoes, therefore, are often a direct result of plate movement. There are three general areas where volcanic activity occurs.

1. Subduction zones: Lava is produced as oceanic plates subduct and malting of rock occurs. When this occurs when only oceanic plates are involved, volcanic island arcs are formed. (See figure 9.10) If oceanic and continental plates are involved, usually a volcanic mountain range will be formed along the margin of the continent. (See figure 9.9) Can you think of examples for these?
2. Divergent zones: As new ocean crust (basaltic lava) is formed at spreading plate margins ridges of volcanic mountains may form. Examples? (See figure 9.6)
3. Hot spots: In addition to plate boundary volcanic activity, there is another type of volcanic activity related to plumes. Surface indications of plumes are spots where they emerge through weaker portions in the overlying layers in the crust at locations called hot spots. (See figure 9.15) There appear to be more than 100 hot spots that are active on our planet. They can occur in the middle of plates in the right circumstances. They can break up plates and drive plates apart. It is believed that they are responsible for such examples as the Hawaiian Islands (See figure 9.14) and Yellowstone Park. They are sometimes located by identifying volcanic activity that is not related to plate boundaries.

C. Mineral resources: By knowing past plate movements, the occurrence of valuable mineral resource deposits on one continent can lead to the assumption that they might also occur on another previously united continent that is now some distance away. Such could happen by correlating the diamond fields in west Africa with the counterpart in northeast South America. Plate tectonics is also important economically, because it affects the location of the earth's surface minerals. In addition, it directly affects the processes by which minerals are concentrated into exploitable ores; Many mineral deposits are found in the vicinity of plate subduction zones, past and present.

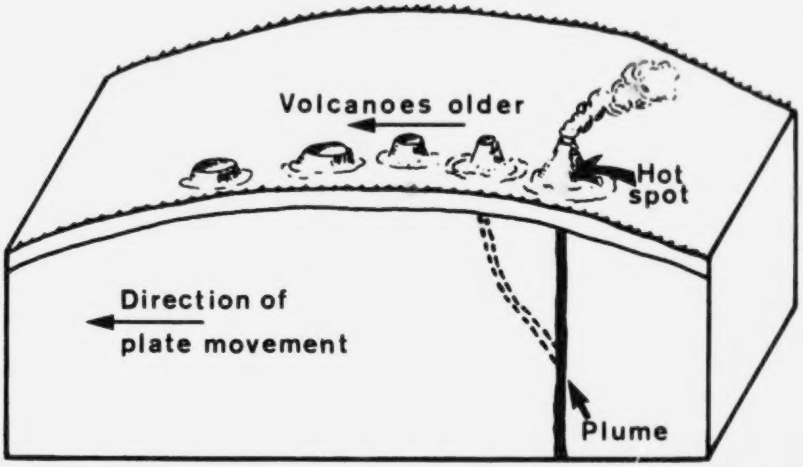


Figure 9.14. Illustrates how hot spot activity has created the Hawaiian Islands as the plate moves across the hot spot.

D. Energy sources: Regions located near subduction zones and hot spots have a potential source of cheap power just below their feet: geothermal energy. Even now, people in such countries as Iceland and New Zealand are using this power source to produce electricity and heat.

E. Biological changes: The effects of plate tectonics show up in the fossil record and provide insight into the migration of plants and animals, wholesale extinctions, and rapid bursts of evolution.

VI. Summary: Continental drift was originally considered to be an outrageous geologic hypothesis. It was initially proposed as taking place by continents "plowing" through the sea floor. This was difficult to accept, and no admissible mode of movement had been proposed or identified. Eventually a mechanism, convection cells, was proposed and is generally accepted today. In the past 20 years, several geologists, working independently, have made discoveries that resulted in the development of the plate tectonics concept. Briefly, we no longer think of the continents drifting through the sea floor. Rather, we now see them as passengers riding on thick plates of lithosphere that are composed of the crust and parts of the upper mantle. The plates either spread apart from each other, collide, or slide horizontally by each other. They are carried along by convection currents within the underlying mantle. With a snap, crackle, and pop, the plate movement causes earthquakes, volcanoes, mountains, new ocean basins, mineral resources, energy sources, and biological changes. WOW!!!

SEE ACTIVITY 9.2

SEE ACTIVITY 9.3

Extra Reading: If you are interested in further reading, the article "Disasters: 'God Fought the Devil,'" *Newsweek*, LXXXVIII, August 30, 1976, follows the chapter. You may also refer to the article "Core of the Matter" in Chapter 8, page 201.

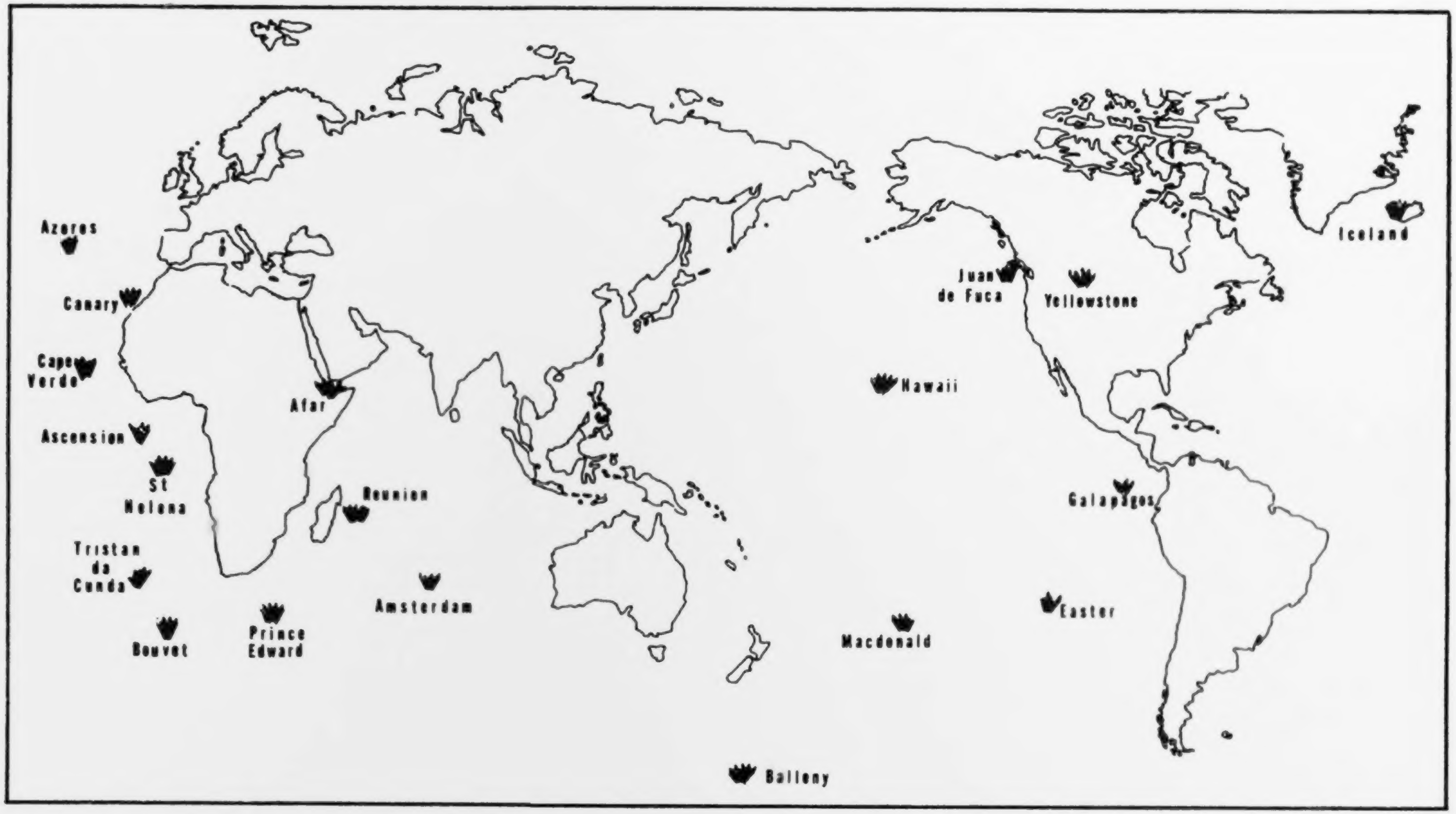

Azores
Canary
Cape Verde
Ascension
St Helena
Tristan da Cunda
Bouvet
Prince Edward
Afar
Reunion
Amsterdam
Juan de Fuca
Yellowstone
Iceland
Hawaii
Galapagos
Easter
Macdonald
Balleny

Figure 9.15. The unartistic blobs are supposed to represent flames which in turn represent the location of major hot spots of the world.

DISASTERS:

'God Fought the Devil'

At the first thundering shock, Filipino soldiers stationed along the coast of Mindanao raced out of their barracks firing their rifles into the air. They thought they had been attacked by Muslim guerrillas, but they soon realized that they were caught in a massive earthquake. The tremor tore apart a dozen towns, and then sent three 18-foot walls of muddy, red water surging across the Moro Gulf. When the tidal waves receded, stranded sharks squirmed in the treetops and whole hamlets of bamboo fishing huts were gone without a trace. More than 5,000 Filipinos died and 90,000 others lost their homes in the country's worst recorded natural disaster. "God came down and fought with the devil," said one bewildered survivor. "It can be the only reason for so much destruction."

Around the world last week, natural disasters struck with an almost supernatural frequency. Earthquakes rocked central China's Szechwan Province and the Molucca Islands in Indonesia. Smaller tremors rattled Turkey, Japan and Chile. And on the French island of Guadeloupe in the Caribbean, a 4,868-foot volcano called Soufrière threatened to explode with the force of several atomic bombs. Nearly 72,000 people fled the banana and sugarcane plantations at its base after scientists warned that an incandescent gas cloud could sweep down and incinerate the area's inhabitants in an instant.

Source: Newsweek, LXXXVIII, (August 30, 1976), pp. 56,57.

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A 30-Megaton Bomb: The fears about Soufrière were as much historical as scientific. Mount Pelée on nearby Martinique erupted in 1902, claiming nearly 40,000 lives. "We live with the memory of Pelée," said one of the scientists on Guadeloupe. Soufrière began rumbling in March, and last month it started belching clouds of gas and ash. Two weeks ago, a series of small tremors caused Prof. Robert Brousse, head of the scientific team, to call for the evacuation. Brousse predicted that Soufrière could explode with the force of a 30-megaton bomb, and early last week when a strong quake struck 2 miles below the peak,it seemed that his prediction might be put to the test. But then the tremors faded, and when Brousse once again hiked to the summit, he found—for the moment, at least—nothing stronger than a trade wind.

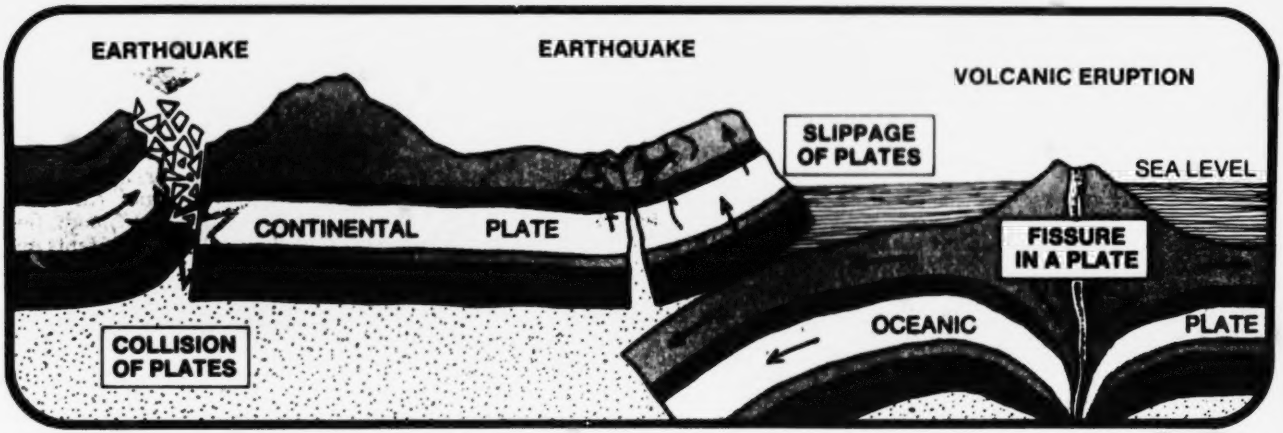
Nineteen seventy-six may yet be known as "The Year of the Upheaval." Like the powerful quakes that hit Guatemala, northeastern Italy, Russia and China earlier this year, last week's shocks probably stemmed from the movement among a dozen or so vast plates of rock on which the world's land masses rest. According to the theory of "plate tectonics," these rocky slabs slowly grind against each other with gigantic force, causing earthquakes and tearing open vents for the upwelling lava in volcanoes (sketch). "China is part of the Eurasian plate, and it is being battered on two sides," says Robert Wesson of the U.S. Geological Survey. From the south, the Indian plate is pushing against the Himalayas, while from the east the Pacific plate is wedging itself under mainland China at the rate of 4 inches a year.

Earthquakes occur at a fairly steady pace, scientists say—about 50,000 a year, most of them minor. But this year the "great" quakes (8 or above on the Richter scale) have been three times more numerous than usual, leading scientists to conclude that a three-year slowdown of major disturbances may have been reversed. And because some of the giant quakes have hit populated areas, they have been more lethal than usual.

Devastation: The Philippine quake measured 8 on the Richter scale (as againast 8.2 for the recent Chinese temblor, the worst recorded anywhere in the world for the past dozen years). It destroyed 80 per cent of Cotabato, the city of 70,000 that was near the epicenter, and badly damaged many other towns. The devastation was multiplied because the quake occurred beneath the sea floor in the mouth of the crescent-shaped Moro Gulf. The resulting tidal waves swamped 500 miles of shoreline. Thousands of villagers were swept out to sea.

Because the Moro coast is the center of the Philippines' war against secessionist Muslim guerrillas, the government was anxious to demonstrate its concern. President Ferdinand Marcos ordered round-the-clock rescue operations by the army and air force and flew to Mindanao with his Cabinet. "Most of those suffering are Muslims, and only a few Christians have been affected," he told relief coordinators. "The Christians must show the concern and sympathy that will enable them to live in cooperation with their Muslim brothers." Marcos also appealed to Filipino nationalism by spurning President Ford's offer of helicopters from the amphibious assault ship U.S.S. Tripoli and a flight of C-130s to aid the relief effort. Filipinos should "not look as if we are beggars," Marcos declared. Following China's lesson in self-reliance, the Philippines planned to depend primarily on its own efforts to heal its devastating wounds.

—KIM WILLENSON with PAUL BRINKLEY-ROGERS in the Philippines, ANDREW JAFFE on Guadeloupe and CHARLES PANATI in New York



Oliver Williams

Why the earth moves: Giant land masses grind and slip against each other, tearing open vents for the lava in volcanoes

Chapter 9: Problems and Questions

1. List some evidence used to support the theory of plate movement.

2. What relationship does continental drift have to the theory of plate tectonics?

3. Explain how earthquakes, volcanism, ocean ridges, and ocean trenches relate to plate tectonics.

4. Name and explain the three (3) kinds of movement possible along plate boundaries.

5. Using the plate tectonic theory, explain how ancient sea-dwelling fossils could be on top of Mount Everest in Tibet.

6. Name and locate the major plates relative to existing continents.

7. Discuss the possible cause(s) of plate motion.

8. Explain the existence of the Hawaiian Islands.

9. Explain the importance of plate movement to southern California.

10. Discuss the importance of plate tectonics to the study of geology and to world economics.

11. Explain why the study of plate tectonics could be important to biologists.

Unit IV: Internal Processes

CHAPTER 10: Earthquakes

- I. Introduction

- II. Earthquake Origins
  - A. Plate Boundaries
    - 1. Faulting
    - 2. Sudden Volcanic Explosions
  - B. Pressure Changes
  - C. Bomb Blasts
  - D. Lubrication

- III. Effects of Earthquakes
  - A. Sounds
  - B. Cracks
  - C. Landslides
  - D. Cracks in Bedrock
  - E. Tsunami
  - F. Destruction by Fire
  - G. Loss of Lives

- IV. Detection and Location of the Epicenter

- V. Earthquake Measurement
  - A. Intensity
  - B. Magnitude

- VI. Earthquake Prediction
  - A. Scientific Instruments
    - 1. Tiltmeters
    - 2. Creepmeters
    - 3. Magnetometer
    - 4. Seismograph
    - 5. Radon Gas Detector
  - B. Human Observation
  - C. Prediction Today

- VII. Reducing Earthquake Impact
  - A. Problems
  - B. Solutions
    - 1. Awareness Campaigns
    - 2. Drills
  - C. Pre-earthquake Planning
    - 1. Collect and Update Information
    - 2. Use of Seismic Risk Maps
    - 3. Land Use Planning
    - 4. Building Standards
    - 5. Increase Prediction Potential

VIII. Earthquake Control

IX. Summary

Related Activities

Vocabulary

Locate the epicenter of an earthquake.

Plot earthquake distribution on a world map.

Problems and questions

Earthquake Geo Facts

Throughout the centuries, earthquakes and their resultant fires, floods, and waves have been the greatest natural destroyer of life and property. They have killed, on the average, some 15,000 people per year.

The length of an earthquake averages about 30 seconds.

Energy released from some of the strongest earthquakes has been compared to that released from 10 to 12 million atomic bombs of the Hiroshima type.

In the immediate vicinity of a large earthquake, land waves can occur. These waves of the earth's surface can vary from several centimeters to several meters in height.

Slippage along the San Andreas Fault of California has been 560 kilometers (350 mi). One might wonder how many earthquakes took place during that slippage.

Aristotle, fourth century B.C., believed earthquakes were caused by air and other gases trying to escape from caves deep within the earth.

There are about 1,000,000 detectable earthquakes per year.

By the year 2000, at least 75,000,000 Americans will be living near or established on the very edge of active earthquake faults.

Of the 100 or so giant earthquakes in this century, only one occurred in California. However, except for Alaska and perhaps Hawaii, California has the most earthquakes in this country.

The greatest earthquake in the United States occurred in New Madrid, Missouri, in 1811 and 1812.

Chapter 10: Word List

Creepmeter
Earthquake
Earthquake intensity
Earthquake magnitude
Elastic-rebound
Epicenter
Fault
Focus
Magnetometer
P-wave
S-wave
Tiltmeter
Tsunami

SAN ANDREAS Fault Zone
10W30 Less Stress Fault Oil

UNIT IV: INTERNAL PROCESSES

Chapter 10: Earthquakes

I. Introduction: Thousands of years ago, humans wandered to earthquake-prone areas and were at the mercy of the restless earth below them. Because they did not understand the scientific cause of such movement, they explained it by superstition or religion. Early Indians believed that the earth was supported by a tortoise, and an earthquake resulted when the beast took a step. Japanese legend told of the giant catfish Namazu-e causing earthquakes by flopping about in his home far beneath the earth. Still others explained earthquakes as the vengeance of an angry god or gods; therefore, people tried to appease the gods by behaving themselves. Their questions about earthquakes went unanswered until the last century. Now, it is known that an earthquake is the sudden movement of the land surface, generally along a fracture, caused by the rapid release of slowly accumulated strain in crustal rocks. This chapter will discuss the fact and fantasy of earthquakes.

II. Earthquake origins: The violent motion experienced during an earthquake can have one of several sources.

A. Plate boundaries: As you should recall, there are three different kinds of boundaries along the edges of plates--divergent plate boundaries, convergent plate boundaries, and lateral-motion plate boundaries. It is in the subduction zone of convergent plate boundaries that most of the world's earthquakes occur, especially around the Pacific Ocean. In addition, the horizontal movement that occurs along lateral-motion plate boundaries creates frequent shallow earthquakes. (See Figure 10.1) Earthquakes in these zones result from two processes.

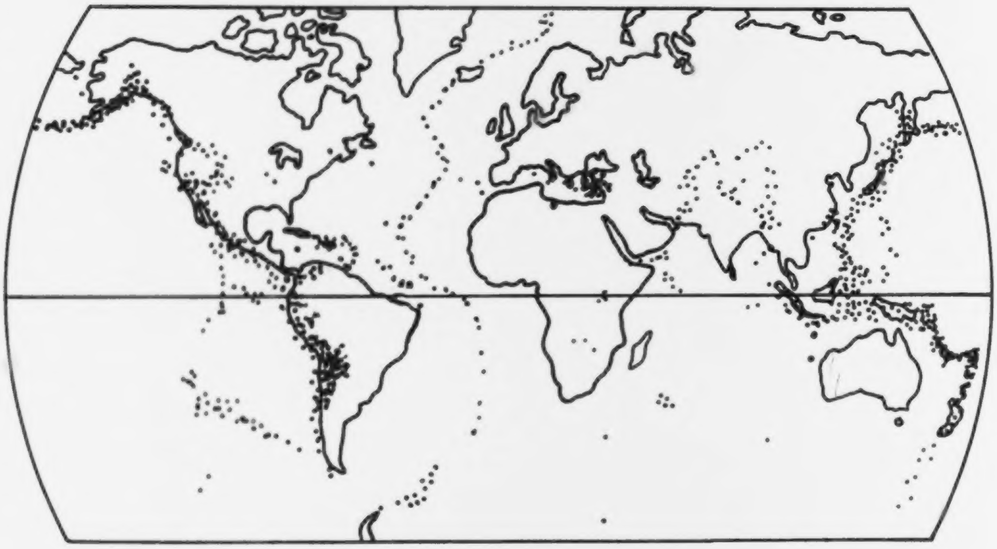


Figure 10.1. The dots indicate the distribution of earthquake epicenters throughout the world.

1. Faulting: A fault is a crack in crustal rocks along which movement takes place. Each side of the bedrock slips or moves. The movement can be in any direction, but if the movement is sudden, an earthquake results. The mechanism of earthquakes is not known, but there are some theories. The most widely accepted is the elastic-rebound theory. When a spring is compressed, it is elastically deformed. After it is released, the spring returns to its original shape. The ability of an object to return to its original shape after being deformed is elastic-rebound. Forces are applied to the earth's crust to deform it. However, when the tension becomes too great, the rocks snap, and energy is released in the form of an earthquake. This results in a tear in the crust. The deformed rock can then return to its original shape. (See Figure 10.2)

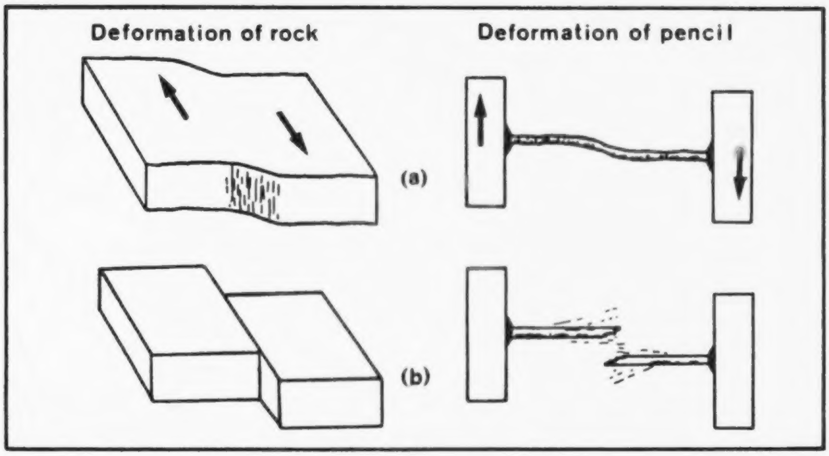


Figure 10.2. Illustrates elastic-rebound in rock and wood. A chunk of the earth's crust is shown on the left and a pencil on the right. (a) illustrates the slow deformation of the crust caused by internal pressure. (b) shows that when the pressure becomes too great, rupturing or faulting occurs, producing an earthquake. Earthquakes along old faults result from excessive pressure.

2. Sudden volcanic explosions: Occasionally, explosions occur near volcanic eruptions because gases become trapped, accumulate, and violently escape. The resulting explosion can also cause the earth to tremor. In addition, the possibility exists that the explosion could cause a fault to slip. Even though volcanic explosions do cause earthquakes, they are usually felt within just a small area.

B. Pressure changes: If there is a change in pressure either below the ground or above the ground, faulting can result. A change in pressure below the ground can occur from pumping out such things as water or oil. Sediment accumulating on top of the ground can cause a pressure change great enough to trigger an earthquake.

C. Bomb blasts: Bomb blasts, in rock quarries for example, or perhaps underground explosions, can jar the earth enough to start a small earthquake by unleashing some accumulated stress in a fault zone.

D. Lubrication: In recent years, injection of liquid waste materials into old fault zones has allowed the rocks to shift and caused inactive faults to become active once again. (In that case, it was their "fault.")

III. Effects of earthquakes: Any casual observer (if anyone can be casual during an earthquake!) will notice several things happening during an earthquake.

   A. Sounds: There are booming noises, claps of thunder, explosions, sharp snapping or tearing sounds, sounds like heavy bodies falling, and/or rumbling of heavy vehicles.

   B. Cracks: During a severe earthquake, the ground may open and close, rise and fall several times. Contrary to popular belief, however, the cracks are not wide nor deep enough for someone or something to be swallowed up when they close. If the cracks are near rivers or shorelines, sand and water may shoot up. In volcanic areas, gases may escape from these cracks.

   C. Landslides: When soil on a steep surface is loosened by an earthquake, a landslide may occur. In 1959, an earthquake in Yellowstone Park caused a large landslide that dammed a river to create a lake (and many problems).

   D. Cracks in bedrock: Bedrock will crack and move. The 1811 earthquake in New Madrid, Missouri, resulted in a stretch of land 24 kilometers (15 mi) and 8 to 13 kilometers (5 to 8 mi) wide being raised 4 to 7 meters (15 to 20 feet). This change is visible today. A lake even resulted from the change in topography. However, most movement of bedrock is not so clearly seen at the surface.

   E. Tsunami: An earthquake can cause disturbances in ocean water by causing the ocean floor to rise or fall, creating traveling ocean waves called tsunami. (See Figure 10.3) These are sometimes incorrectly called tidal waves. Because the waves appear simply as a rise in the ocean level, they cannot be seen from the air. However, as they approach land, they build up in height becoming as much as 28 meters (90 ft) high. Because of the concentration of seismic activity around the Pacific, tsunami occur primarily in this area. An international warning system has been established in recent years for people living in the Pacific earthquake belt. As soon as an earthquake occurs which may be accompanied by a tsunami, people receive warning to move to higher ground, thus reducing the hazards. Have you or anyone you know been in Hawaii when a tsunami warning was issued? Share this experience with the class.

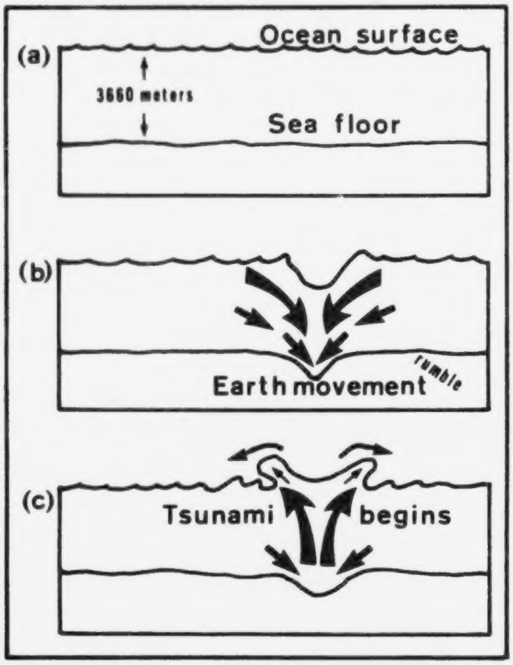


Figure 10.3. An illustration of the beginning of a tsunami.

F. Destruction by fire: In the San Francisco earthquake of 1906, only 5 percent of the damage was caused by the earthquake. For three days, fires, started by overturned lamps and stoves, could not be put out because the earth movements had broken water mains.

G. Loss of lives: The total number of lives lost in earthquakes throughout history has been estimated at 15 million. (See Table 10.1)

IV. Detection and location of the epicenter: (Before beginning this section, you may wish to refer to Chapter 8 to review the terms P-wave, S-wave, and focus.) The epicenter of an earthquake is the point on the earth's surface that is directly above the focus. (See Figure 10.4)

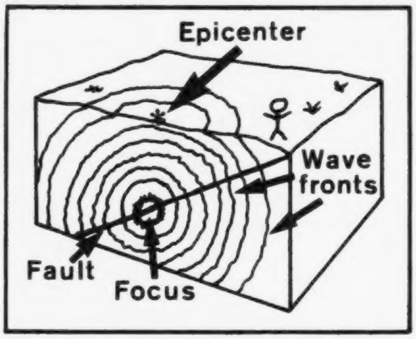


Figure 10.4. Illustrates the relationship between the focus and epicenter of an earthquake.

Through evidence accumulated from thousands of earthquakes, it has been possible to determine the distance from the earthquake epicenter to the recording station by timing the difference in arrival time between the P- and S-waves. (See Figure 10.5)

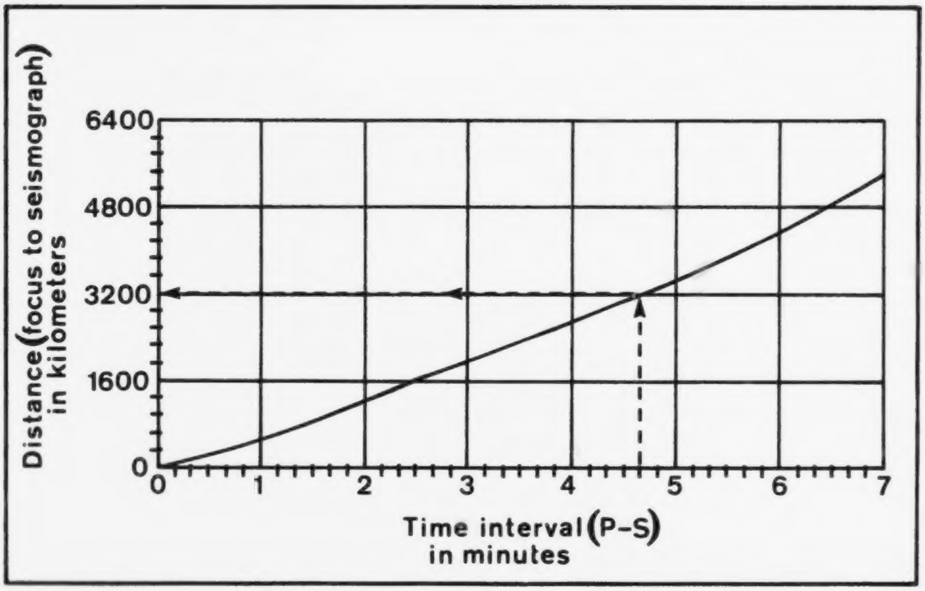


Figure 10.5. Chart of time interval between P- and S-waves giving focus-to-station distance.

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Table 10.1. Selected Major Disastrous Earthquakes

Date	Location	Extent of Disaster
1556	China	830,000 dead (highest death toll in history).
1755	Portugal	60,000 dead; one of the strongest quakes in history; tsunami caused waves on Scotland; aftershocks continued for months.
1811-1812	New Madrid, Missouri	Thousands of shocks felt over most of the United States; caused Mississippi River to flow upstream; created Reelfoot Lake, Tennessee; changed shape of land and land boundaries.
1897	India	Severe; upheaval of land; fault scarp over nine meters (30 ft); buildings within 77,700 square kilometers (30,000 mi^2) damaged or destroyed; aftershocks continued two years.
1906	San Francisco, California	700 dead; horizontal movement along San Andreas fault zone; extremely severe quake, destroying most of the city.
1908	Sicily	75,000 dead; shoreline level dropped several meters; tsunami.
1920	China	180,000 dead; many buried in landslides of loess.
1923	Japan	143,000 dead; Yokohama and Tokyo destroyed; tsunami; extensive fires.
1960	Morocco	10,000 dead, 12,000 injured; destroyed city of Agadir, population 33,000.
1964	Alaska	116 dead; severe with widespread destruction; tsunami; caused extensive damage in Pacific Northwest.
1972	Managua, Nicaragua	10,000 dead; enormous damage to Managua, because town was built on a foundation of unconsolidated lake-bed sediments.
1976	Guatemala	23,000 dead; shock felt from Mexico to Costa Rica; major shock area 9,143 square kilometers (3,530 mi^2). The following week, another quake with 19,000 dead, 66,000 more injured; over 1 million homeless.
1976	China	First quake registered 8.2 on Richter scale, followed 16 hours by another, 7.9 on Richter scale; government refused to give statistics; "Great losses to people, life, and property."
1978	Iran	25,000 dead; leveled village of Tabas.
1979	Near coast of Guerrero, Mexico	5 dead, many injured; 8 villages destroyed leaving 7,500 homeless; heavy damage to 174 buildings in Mexico City (300 km northeast of the epicenter).

By using the graph, one can quickly estimate the distance from the focus to the station for any time interval up to a seven minute limit covered by the chart. For example: You are in the geology classroom in your high school with your trusty seismograph. The seismograph records the P-waves from an earthquake occurring in an as yet undetermined location. Four and two-thirds minutes later, the S-waves are recorded. Now the chart in Figure 10.5 comes in handy. First, extend a vertical line from the 4-2/3 minutes point on the Time interval portion of the chart (that portion of the chart across the bottom) up to the curve. Next, draw a horizontal line from the intersection on the curve, left to the Focus-to-seismograph portion of the chart (the vertical portion of the chart on the left). The horizontal line intersects the distance axis and tells you that the earthquake was about 3,200 kilometers (2,000 mi) from your school. You now know how far away the earthquake was but not the direction. Two other station readings are necessary. Upon receipt of these readings, draw circles of the proper diameter (representing distance from each seismograph) centered at each of the stations on a United States map. (See Figure 10.6) You have located the epicenter of the earthquake at the point of intersection of the three circles.

SEE ACTIVITY 10.1

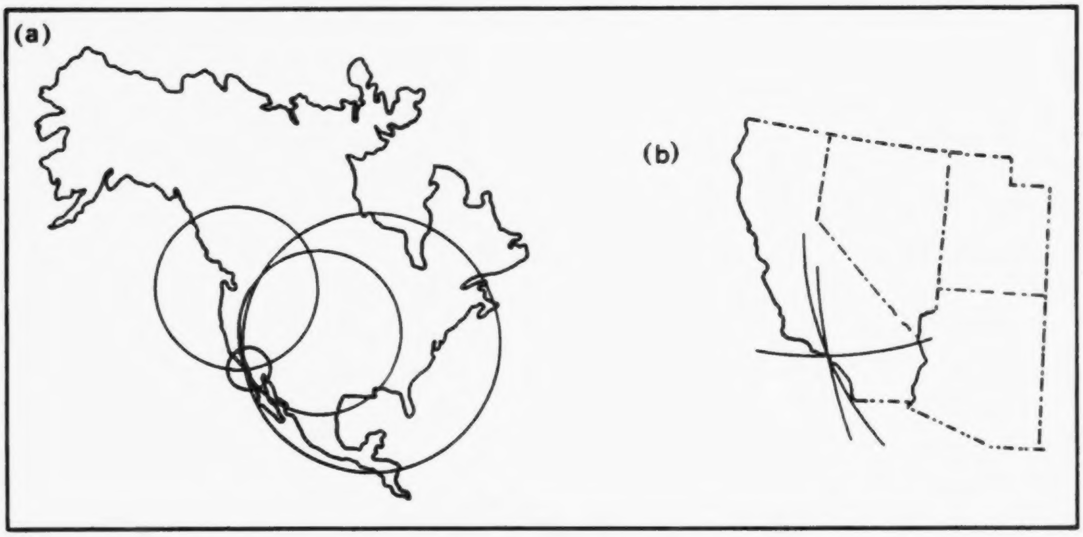
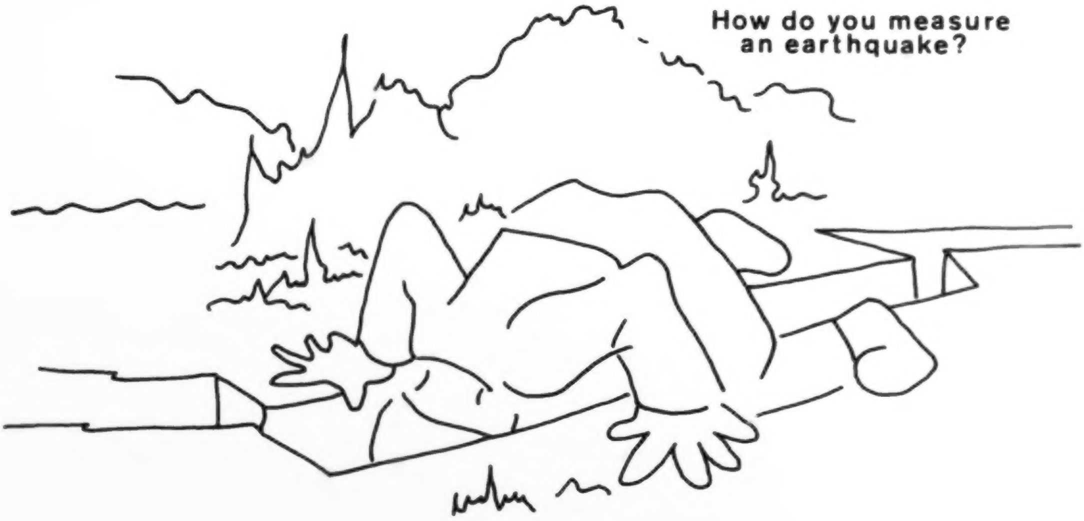


Figure 10.6. (a) is a North American map showing how the epicenter of an earthquake is determined. This one occurred at the intersection of the three circles. They represent the distance of the epicenter from each of three seismic stations--O'Fallon, Illinois; Seattle, Washington; and Denver, Colorado. (b) is a closeup of the intersection in California, where the earthquake occurred.

V. Earthquake measurement: Actual measurements of earthquakes are difficult to make, so at the present time, scientists use measures of magnitude and/or intensity.

   A. Intensity: The intensity of an earthquake is the strength of the earthquake; it is a person's measurement of how an earthquake affects him/her, the structures built by him/her, and the earth's surface. A number is assigned to different intensity levels, but it must be remembered that because the effects of shaking are different at different locations, there are many intensities measuring one earthquake. An Italian seismologist, Mercalli, proposed a scale, and now the most widely used intensity scale in America is the "Modified Mercalli" (1956).



B. Magnitude: When an earthquake occurs, a seismograph is able to measure the total seismic energy released in the form of earth waves. This is the magnitude, and while there are many intensities, depending upon the location, there is only one magnitude. This scale, known as the Richter scale, is the most commonly used measurement today because it is more scientific. (See article "How Earthquakes Are Measured" at the end of the chapter.)

VI. Earthquake prediction: At the present time, it is still not possible to predict earthquakes. However, scientists feel they are nearing this goal. There are several basic approaches to earthquake prediction.

A. Scientific instruments: Certain occurrences have been observed before a quake. There are several instruments available to measure these changes, and they are placed in as many earthquake-prone areas as possible.

1. Tiltmeters: This instrument records minute changes in the slope of the land near a fault. The landscape often shows wobbly-like behavior before an earthquake, and tiltmeters detect this movement.
2. Creepmeters: Creepmeters consist of a wire (or laser beam) stretched across a fault to record horizontal movement along the fault.
3. Magnetometer: A magnetometer measures changes in the earth's magnetic field. Stress creates an increase in conductivity of the rocks far below the surface, which therefore changes the magnetic field in that area. This can be measured by the magnetometer.
4. Seismograph: Since the seismograph measures and records seismic waves, it can be useful in prediction. Seismic waves show a distinct change in speed before an earthquake and, of course, the seismograph can record this change.
5. Radon Gas Detector: In recent years, scientists have found that radon gas is emitted just prior to an earthquake.

B. Human observation: The Chinese people take a simpler, less expensive, sometimes inaccurate approach to earthquake prediction. While they still use instruments, the Chinese respect most indicators that any people, especially farmers, might notice. Animals tend to act nervous and restless before a quake--chickens panic, pigs refuse to enter pigsties, rats and mice leave their holes, and hibernating snakes slither out onto the ice. Water in deep wells tends to be murky. Thousands of Chinese are told what to look for in their environment, constituting an earthquake prediction network. Apparently, they have made some of the most accurate predictions in the world. Hopefully, an earthquake prediction network

similar to China's will become established in the United States. Recently, several thousand students in California were given specific instructions on potential earthquake symptoms. Time will tell about the effectiveness of this approach.

C. Prediction today: At this point in time, a combination of people and instruments would seem to constitute the most effective means of earthquake prediction. By spreading thousands of people to monitor other subtle changes not detected by instruments, thousands of lives may be saved.

VII. Reducing earthquake impact: The impact of earthquakes, including their possible threat, poses many problems. Some of these problems cannot be solved. However, it is important to be aware of them.

A. Problems: Earthquake prediction can create unexpected hazards. If advance warning of one or two years is given, there is a potential impact on the target area. Economic disaster can result from a decline in property values, from a decline in business activity and employment opportunities, and from a reduction in public services, to mention a few. Despite the fact that early warning can seriously reduce risk of death or injury, a realist must also consider all implications of earthquake prediction. In light of the problems just posed, one may conclude that the least that can be done is to make the threatened area as safe as possible in preparation for an imminent earthquake.

B. Solutions: The Chinese have the most reliable solution to reducing earthquake impact at this time. Upon predicting an earthquake, they simply move their people to safer ground. This action has an interesting twist to it which eliminates our people from its use. The Chinese are not afraid of failure or of making fools of themselves. If their prediction did not work, they still continue to predict and move the people out. In the United States, one or two failures of accurate prediction would probably curtail much future action. We are afraid of failure. However, there are some avenues open to use to reduce earthquake impact.

   1. Awareness campaigns: There should be advertising campaigns to inform the people as to safety procedures during an earthquake. Included would be instructions to go outside, where it is safest, unless there is great danger of falling rubble. In that case, doorways provide support that is safer to stand under.
   2. Drills: Just like firedrills, there should be earthquake drills. Emergency vehicles would be positioned in open spaces where they would not be trapped by collapsing structures or falling trees. Hospitals should be ready. National Guard or Army units should be on standby. People should head for safety. Ideally, water level in dams should be lowered before a quake. In a drill, of course, this is impossible. However, dam operators should go through the motions during a drill.

C. Pre-earthquake planning: In 1971, earthquake experts from 28 nations met in San Francisco. They made several recommendations regarding proper planning in earthquake-prone areas. These include the following.

   1. Collect and update information: On a national and international level, all information on engineering, geology, and seismology should be collected and updated on a regular basis.
   2. Use of seismic risk maps: In areas where earthquakes may occur, seismic risk maps based on the latest geological data should be developed. These maps should be as detailed as possible and include information on not only the fault itself, but as to the nature of the surrounding rocks and sediment as well.
   3. Land use planning: States and/or cities should develop land use plans, based upon seismic risk maps to minimize development in high risk areas. The kind of material on which a structure is built is often more important than the relative closeness to the epicenter of the earthquake.
   4. Building standards: Codes should be established so that all new structures in earthquake-prone areas be built to minimize the danger of collapse. In addition, older buildings should be inspected and if needed brought up to standards or demolished.
   5. Increase prediction potential: High risk areas should have proper scientific equipment (See IV.A.) to monitor possible earthquake activity and a warning system set up to make citizens aware of possible earthquake activity.

VIII. Earthquake control: Man has begun to conquer space and harness the atom, but control of the forces within the earth is still beyond him. However, an incident in Colorado gave birth to an idea for control. In 1962, outside Denver, liquid chemical wastes were dumped into a newly dug well that was more than three kilometers (2 mi) deep. Six weeks and 30,257,186 liters later, a series of earthquakes were recorded in the area. A similar occurrence was recorded in northwestern Colorado. In both cases, apparently the liquid reduced the friction along the faults, allowing them to slip easily. Thus arose the idea of injecting liquid into wells along a major fault. This would then allow the fault to creep smoothly rather than explode because it has been locked. As yet, no one is prepared to try an earthquake of human origin with controlled subsurface explosions, but they are a future possibility for earthquake control.

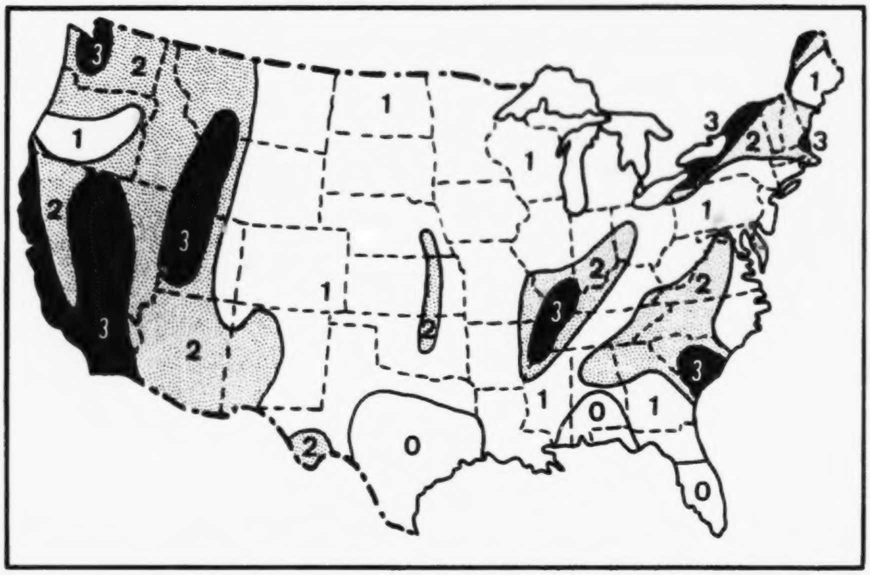


Figure 10.7. This United States map shows the approximate zones of seismic risk in the country. Zone 0 represents no risk of damage; Zone 1 represents risk of minor damage; Zone 2 represents risk of moderate damage; Zone 3 represents risk of major damage.

IX. Summary: Throughout the centuries, earthquakes and their resultant fires, floods, and waves have been the greatest natural destroyer of life and property. They are caused primarily by plate movement and/or associated volcanic explosions, but in addition, they can result from bomb blasts and pressure changes. Their effects often resemble something that United Artists would produce in hopes of receiving an Oscar for Special Effects. Unfortunately, it is for real instead of for viewing at your local movie theatre. Earthquake measurement can be made in terms of the seismic energy released--magnitude, or its effects on people and their structures--intensity. Earthquake prediction still remains a dream, but scientists are coming closer to solving some of the earthquake's elusive riddles as they learn more about the earth's interior. With proper planning and a great deal of common sense, the impact of earthquakes can be reduced. They will never be eliminated, but perhaps they can someday be controlled. Until then, fasten your seatbelts!

SEE ACTIVITY 10.2

Extra Reading: If you are interested in further reading, the articles "When the Earth Shakes in Illinois" and "How Earthquakes Are Measured," published by the Illinois State Geological Survey, follow the chapter. You may also refer to "Core of the Matter," page 201 and "Disasters, 'God Fought the Devil'," page 226.

ILLINOIS STATE GEOLOGICAL SURVEY
Urbana, Illinois 61801

GEOGRAM 4
October 1975

WHEN THE EARTH SHAKES IN ILLINOIS

Myrna M. Killey

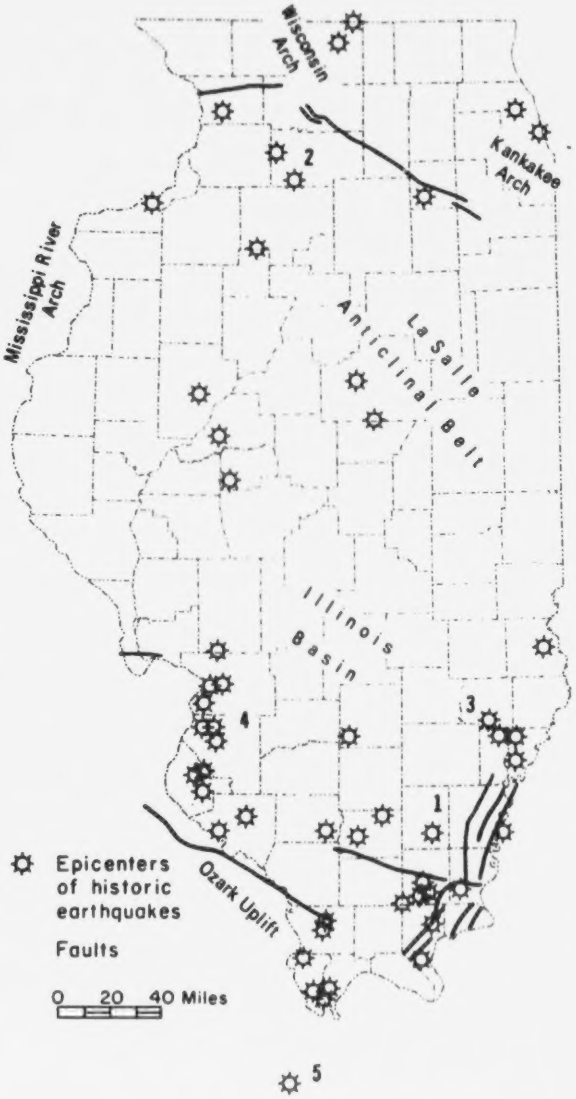
From time to time people in Illinois have reported feeling the earth shake. They may have heard rumbling noises like those made by heavy trucks passing by or have seen various objects mysteriously moving about—pictures swinging on the walls, dishes dancing on shelves, or parked cars rocking. People recognize these shakings as earthquakes and may wonder why earthquakes occur in Illinois.

The answer to that question is a complicated one. Essentially, earthquakes result from the build-up of great stresses in various parts of the earth. These stresses take the form of pulling, pushing, and shearing forces. Why such stresses build up is still not clearly understood and is the subject of much study and discussion among geologists and geophysicists. However, it is generally believed that these forces stretch the rocks and finally cause them to break. The breaks are called *faults* when the blocks of rock on either side of the break are displaced in relation to each other. In Illinois, the amount of displacement along faults observed in rocks near the surface is from a few inches to more than 3,000 feet. The faulting relieves the stress in the rocks and is the immediate cause of earthquakes. Sometimes faulting takes place at the earth's surface, but more often it occurs at great depth and cannot be seen on the land surface. In either case, faulting occurs where the rocks are weakest and offer the least resistance to stress. By noting places where faults can be seen at the surface and where long arches (*anticlines*) and troughs (*synclines*) occur in the rocks near the surface, geologists can pinpoint past zones of weakness in the rocks. These zones are the most likely places for future earthquakes to take place. They may extend for hundreds of miles.

When faulting takes place, the great amount of strain that had built up in the rocks is released suddenly and a series of vibrations, called seismic waves, radiates away from the fault. Although the release of stress is sudden, shaking may occur for some distance and has been known to last for hours. The nature of the rocks and the complicated paths along which seismic waves travel determine the extent and duration of the shaking.

The point at which faulting starts and from which seismic-wave energy radiates is called the *focus* of an earthquake. The *epicenter* is the point on the earth's surface directly above the focus. The map (turn page) shows epicenters of earthquakes that have occurred during historical times in Illinois. It also shows some geologic structures that indicate possible zones of weakness in rocks near the land surface.

You may remember some of the more recent earth tremors in Illinois. On the morning of November 9, 1968, an earthquake, centered near Broughton (1 on map) in Hamilton County, shook a large area of the central and southeastern United States. A less powerful quake was felt over a seven-state area in the central United States shortly after midnight on September 15, 1972. It was centered just south of Amboy in Lee County (2 on map) in northern Illinois. A third quake, felt


Wisconsin Arch
Kankakee Arch
Mississippi River Arch
La Salle Anticlinal Belt
Illinois Basin
Ozark Uplift
1
2
3
4
5
Epicenters of historic earthquakes
Faults
0 20 40 Miles

at 6 o'clock on April 3, 1974, was centered near Olney in Richland County (3 on map). Still another quake occurred early in the morning of June 5, 1974, in the Belleville area near St. Louis (4 on map).

As alarming as these quakes might have been, they by no means compare with the series of earthquakes that shook Illinois and the central United States from December 1811 through February 1812. The area around New Madrid, Missouri (5 on map), just south of Illinois along the Mississippi River, was the site of three consecutive quakes, each much larger than any other recorded earthquake in Illinois. A repeat of such events today would cause great loss of property and, possibly, life.

At the present time, geologists are working to find ways to predict when, where, and how large any future earthquakes will be. This information is vitally important to engineers, architects, and planners who design and build homes, hospitals, highways, dams, office buildings, factories, and other important structures. Although we cannot yet predict when and where the next earthquake will occur in Illinois, we can design structures to withstand the damaging effects of the earthquakes.

ILLINOIS STATE GEOLOGICAL SURVEY
Urbana, Illinois 61801

GEOGRAM 7
September 1976

HOW EARTHQUAKES ARE MEASURED

Myrna M. Killey

Photographs and films in news reports of earthquake damage show us in a vivid way how strong some earthquakes are. However, many earthquakes do not cause visible damage. Therefore, pictures are not the only means to describe the strength of an earthquake. In fact, most news accounts mention reports from scientists who refer to the severity of an earthquake by using measures of "magnitude" and "intensity." What do these terms mean?

The *magnitude* of an earthquake is computed from ground movement recorded at seismic stations by instruments called seismographs. Magnitude is the measure of the total seismic energy released by the earthquake. It was originally defined by Charles F. Richter, an American seismologist, to make it easier to compare the differences in amounts of energy released by earthquakes. Magnitude is not directly proportional to the amount of energy released. For example, an earthquake of magnitude 5 does not release only 25 percent more energy than an earthquake of magnitude 4. The earthquake of magnitude 5.5 that occurred in southern Illinois on November 9, 1968, released about 250 times the energy of the southern Illinois quake of magnitude 4.5 on April 3, 1974.

The *intensity* of an earthquake is a measurement of the effects of the shaking, as shown by the damage to property and by the earth deformation felt or observed by people in a particular part of the shaken area. Thus, for any earthquake there are many intensities (dependent upon the location of an observer in the earthquake area) but only one magnitude (measured by seismographs).

The most widely used intensity scale is the Modified Mercalli scale which was introduced in 1931. A Modified Mercalli scale of earthquake intensities and the approximately corresponding magnitudes on the Richter scale can be found in the table on the other side of this page. This table will help you to compare information between past earthquakes and future tremors about which you may read or hear in the news. Magnitudes and maximum intensities of some recent Illinois earthquakes are listed here. Maximum intensity is designated because an earthquake can produce several distinct shocks of different strengths.

	Magnitude	Maximum intensity
November 9, 1968	5.5	VII
September 15, 1972	4.63	VI
April 3, 1974	4.5	VI
June 5, 1974	4.0	V

The initial movements along a fault to relieve the buildup of stress may involve a relatively small area of the fault plane, but after a short interval of time a shift over a much larger area of the fault plane follows. Because tearing and displacement usually occur at great depths, shallower faults that can be seen at the earth's surface may or may not be affected. On the west coast, surface faults are highly active during earthquakes, but in Illinois, there is not yet evidence that recent earthquakes have caused shifts along the ancient fault lines intersecting the bedrock surface.

Sometimes the initial movements in the small area and the shifts in the much larger area of the fault plane occur almost at the same moment so that they cannot be distinguished. However, if the time interval between shocks is great enough to allow them to be distinguished, the first movements are called *foreshocks*. The shift of the rocks at the time of the principal break, or *main shock*, relieves the main stress in the rocks. Following the main shock, a series of adjustments in the rocks results in a sequence of *aftershocks* of gradually decreasing magnitude and frequency.

Instruments to measure magnitude had not yet been invented at the time of the New Madrid, Missouri sequence of earthquakes in 1811-1812, but from historical reports available on the effects and damage of that tremendous shaking, the total energy released in the New Madrid sequence is thought to be equivalent to at least magnitude 7.5 on the Richter scale. The first of the quakes, which took place on December 16, 1811, was estimated to have a maximum intensity of XI.

The so-called "New Madrid seismic region," which includes portions of extreme southern Illinois, southeast Missouri, western Tennessee and Kentucky, and northeastern Arkansas, has historically been an area of frequent earthquakes. In the southern Illinois area, the release of energy has occurred generally as numerous small shocks, most so small that they have caused little or no damage to man-made structures.

MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITIES WITH APPROXIMATELY CORRESPONDING MAGNITUDES*

Intensity		Description of characteristic effects	Richter scale magnitude approximately corresponding to highest intensity reached
I	Instrumental:	detected only by seismography	
II	Feeble:	noticed only by sensitive people	3.5 to 4.2
III	Slight:	like the vibrations due to a passing heavy truck; felt by people at rest, especially on upper floors	
IV	Moderate:	felt by people while walking; rocking of loose objects, including standing vehicles	4.3 to 4.8
V	Rather strong:	felt generally; most sleepers are wakened and bells ring	
VI	Strong:	trees sway and all suspended objects swing; damage by overturning and falling of loose objects	4.9 to 5.4
VII	Very strong:	general alarm; walls crack; plaster falls	5.5 to 6.1
VIII	Destructive:	car drivers seriously disturbed; masonry fissured; chimneys fall; poorly constructed buildings damaged	6.2 to 6.9
IX	Ruinous:	some houses collapse where ground begins to crack, and pipes break open	
X	Disastrous:	ground cracks badly; many buildings destroyed and railway lines bent; landslides on steep slopes	7.0 to 7.3
XI	Very disastrous:	few buildings remain standing; bridges destroyed; all services (railway, pipes and cables) out of action; great landslides and floods	7.4 to 8.1
XII	Catastrophic:	total destruction; objects thrown into air; ground rises and falls in waves	8.1+

* From Holmes, Arthur, 1965, Principles of Physical Geology: Ronald Press, N.Y., p. 901.

Chapter 10: Problems and Questions

1. Discuss three (3) causes of earthquakes.
2. An earthquake has occurred. List physical evidence to support that it was an earthquake.
3. Describe a tsunami, and explain how it is related to an earthquake.
4. Distinguish between an earthquake focus and epicenter.
5. Discuss what other geologic hazards may exist because of an earthquake.
6. You are standing by a fence. An earthquake occurs 16 kilometers (10 mi) away. First, the fence posts go up and down. There is a brief pause, then the posts sway sideways. Relate the motion of the fence posts to P- and S-waves. How does the length of the pause relate to the distance of the earthquake from you?
7. An earthquake occurs in southwestern Missouri. Would the intensity of the quake be the same in St. Louis as in Springfield, Illinois? Why?
8. Discuss the various earthquake detection methods.
9. Discuss the safety measures that could be used to reduce earthquake impact.
10. How are earthquake zones and plate boundaries related?
11. Explain how the Richter scale and the Modified Mercalli scale differ.

Unit IV: Internal Processes

CHAPTER 11: Volcanic Activity

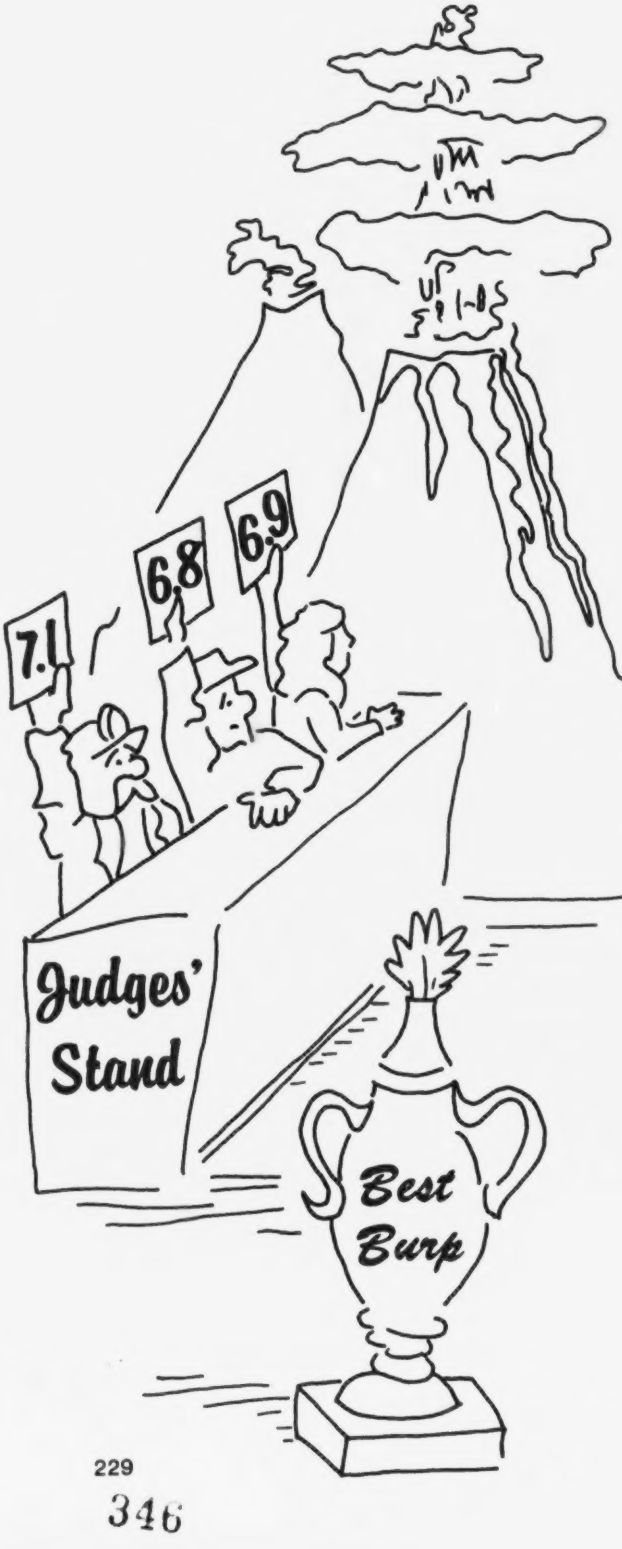
I. Introduction

II. Eruptions of Magma
  A. Mid-Oceanic Ridges
  B. Subduction Zones
  C. Hot Spots

III. Volcanic Products
  A. Gases
    1. Water Vapor
    2. Carbon Dioxide
    3. Sulfurous Gases
  B. Trace Elements
  C. Lava
    1. Silica
    2. Oxides
  D. Rock Types
    1. Basalt
    2. Scoria
    3. Rhyolite
    4. Andesite
    5. Obsidian
    6. Pumice
    7. Tuff and Breccia

IV. Intrusive or Plutonic Features
  A. Types of Structure
    1. Concordant Structures
      a) Sill
      b) Laccolith
    2. Discordant Structures
      a) Dike
      b) Batholith
      c) Stock
  B. Types of Rocks
    1. Granite
    2. Diorite
    3. Grabbo
    4. Peridotite

V. Extrusive or Volcanic Structures
  A. Volcanic Cones
    1. Cinder Cone
    2. Shield Cone
    3. Composite Cone
  B. Volcanic Dome
  C. Lava Plateau



VI. Features in Volcanic Rocks
  A. Smaller-scale Products
    1. Aa Lava
    2. Pahoehoe Lava
    3. Pillow Lava
    4. Pyroclastics
  B. Larger-scale products
    1. Lava Tunnels
    2. Columnar Joints

VII. Life Cycle
  A. Stages of Activity
    1. Active
    2. Dormant
    3. Extinct
  B. Local Volcanism
    1. Stages of Erosion
    2. Caldera
  C. Regional Volcanism
  D. Volcanic Aftermath
    1. Fumaroles
    2. Hot Springs
    3. Geysers
    4. Associated Phenomena

VIII. Destructive Volcanoes in Recorded History

IX. Coexistence--People and Volcanoes
  A. Hazards
    1. Lava Flow
    2. Mudflow
    3. Heavy "Rainfall" of Ash and Dust
    4. Suffocating Gases
    5. Nuee Ardente
  B. Benefits
    1. Fertile Soil
    2. Water Vapor
    3. Carbon Dioxide
    4. Volcanic Rock
    5. Geothermal Energy
    6. Beauty
    7. Ore Deposits
  C. Prediction
    1. Increase in Tilt
    2. Minor Earthquakes
    3. Increasing Temperatures
    4. Increase in Subcrustal Noise
    5. Magnetic Changes

X. Summary

Related Activities

Vocabulary

Identify volcanic structures on topographic maps and aerial photographs.

Plot volcanoes and volcanic areas on a world map.

Problems and questions

Volcanic Geo Facts

In 1883, the eruption of Krakatoa, East Indies, shot particles of pumice and dust into the air causing unusually red sunsets around the world for the next two years. The sound of the explosion was heard 4,800 kilometers (3,000 mi) away.

The mysterious lost continent of Atlantis may have disappeared because of a volcanic explosion.

Active volcanoes in the United States are found in Hawaii, California, Alaska, and most recently, Washington.

Lava from volcanoes reaches temperatures of 1,100° Centigrade (2,000°F).

Lava may travel as fast as 40 kilometers per hour.

No one has ever seen magma.

At present, there are approximately 500 active volcanoes on the earth's surface. There have been 3,294 recorded eruptions, 483 since 1700.

"At one time or another during the last 70 million years, volcanic rocks covered nearly all of the Western States of Washington, Oregon, California, Nevada, Arizona, Utah, Idaho, and large parts of Montana, Wyoming, Colorado, New Mexico, and Texas. Still older volcanic rocks, now largely deformed and metamorphosed, are found in nearly every state." USGS

The Hawaiian Islands are made up entirely of volcanic rocks. One volcano rises nearly 9,150 meters (30,000 ft) from the ocean floor.

Surprisingly, in some areas of the world, mudflows rather than lava have been the major cause of destruction and loss of life during volcanic catastrophes.

Yellowstone National Park was once an area experiencing active volcanism.

Chapter 11: Word List

Melting Pot Terms

Aa
Active volcano
Batholith
Caldera
Cap Rock
Cinder cone
Columnar joints
Composite cone
Concordant structure
Crater
Dike
Discordant structure
Dormant volcano
Erosion
Extinct volcano
Extrusive structure
Felsic
Fissure
Fumarole
Geothermal energy
Geyser
Hot spring
Intrusive feature
Laccolith
Lava
Lava Plateau
Lava Tunnel
Mafic
Magma
Mudflow
Nuee Ardente
Pahoehoe
Parasitic cone
Pillow lava
Plume
Plutonic feature

Pyroclastic material
Shield cone
Sill
Solfatara
Stock
Tephra
Vent
Vesicle
Volcanic bomb
Volcanic cone
Volcanic dome
Volcanic neck
Volcano

Straight Terms

Abrasive
Coexistence
Dissect
Ellipsoid
Erupt
Flank
Incandescent
Intermittent
Parasite
Protrusion
Spindle-shaped
Symmetrical
Therapeutic
Viscous
Volatile
Waning

UNIT IV: INTERNAL PROCESSES

Chapter 11: Volcanic Activity

I. Introduction: The word "volcano" comes from a little island called Vulcano that is located off the coast of Sicily in the Mediterranean Sea. Vulcan was the ancient Roman god of fire and metalworking. It was believed by the people that lived in that area that Vulcano was the chimney of Vulcan's forge. They thought that eruptions occurred as he worked at his roaring, fiery forge beating out thunderbolts for Jupiter (king of the gods) and weapons for Mars (god of wars). Thus the unpredictable, terrifying, and frequent volcanic eruptions were explained to the Roman world. Science now provides a modern society with the definition of volcano as a vent in the earth's surface through which molten rock, heated rock debris, gases, and water vapor are expelled from beneath the earth's surface.

1st ANNUAL LAVA LAUNCH CONTEST
Huge
Big
Medium
Small
Tiny

II. Eruptions of magma: Beneath the surface of the earth, pockets of molten rock-forming material (otherwise known as magma) exist. Because rocks are poor conductors of heat, the heat accumulates from radioactive decay, melting the rock and producing pockets of magma. As the magma expands, it moves upward, seeking areas of less pressure found in weaker portions of the crust. Once the magma surfaces, it is called lava. The super thing about volcanoes (at least to geologists) is that they are the only place where rock is seen in a molten state. There are three areas that are of prime importance in the generation and eruption of magma.

A. Mid-oceanic ridge: This is the location where lithospheric plates in the ocean are pulled apart, and the intervening space is filled with magma. (See Figure 11.1) It is believed that at this location, material from the outer mantle is rising. The outer mantle is composed of the rock peridotite, which is made of the minerals olivine, pyroxene, and small amounts of plagioclase. As the heat increases, the plagioclase melts first, followed by pyroxene, and eventually olivine. If there is only partial melting, the melted mass is rich in plagioclase and pyroxene and is therefore a basaltic magma. Thus, the magma that spills out of the mid-oceanic ridge and oceanic basin volcanoes is mafic.

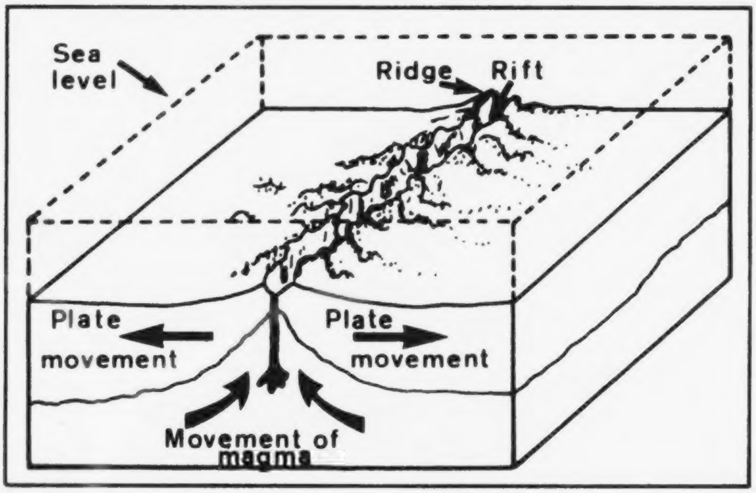


Figure 11.1. Basaltic magma rises between two plates of the earth along the oceanic ridge.

B. Subduction zones: As you remember, the subduction zone is the area in which plates collide. In one situation, the basaltic oceanic lithosphere with its covering of sediment slides under the continental lithosphere into the mantle. (See Figure 11.2) The diving plate is heated by the friction between the moving plates and by the higher temperatures at greater depths. The partial melting of the basaltic plate mixed with the granitic plate produces a lighter colored, felsic magma that is rich in silica. This molten rock rises upward producing either granitic structures of magma if the magma does not reach the surface or andesitic-rhyolitic flows if the magma does reach the surface. The pressures at the roots of the mountains increase the temperatures enough to cause localized melting of some minerals. These melted minerals rise and collect in larger bodies to produce granitic magma chambers. While an oceanic/oceanic subduction boundary will produce volcanic island arcs composed of darker, denser lavas due to melting of the subducting oceanic plate and its later extrusion of that melted material onto the floor of the other oceanic plate.

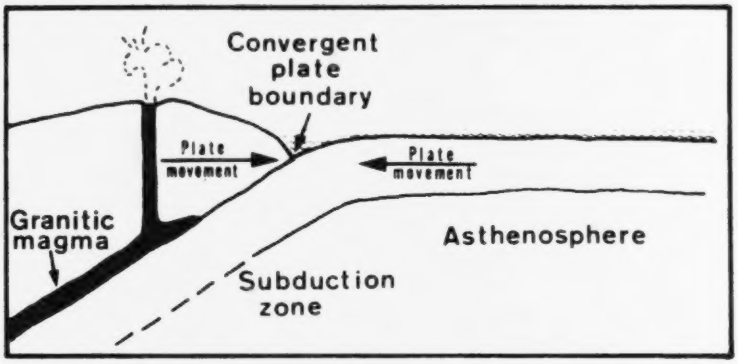


Figure 11.2. Granitic magma is created by scraping material from the diving plate in the subduction zone.

C. Hot spots: It is believed that convection cells exist within the mantle. In review, a convection cell is an area of magma that circulates within the mantle by rising, spreading out laterally and cooling, sinking to be reheated, and then rising again. (See Figure 11.3) Within the convection cell, the plume is that portion of the magma that is rising. The magma in plumes sometimes pokes up through the crust to deliver magma to the earth's surface. This magma is usually mafic in nature. (See Ch. 9 V B 3 for details.)

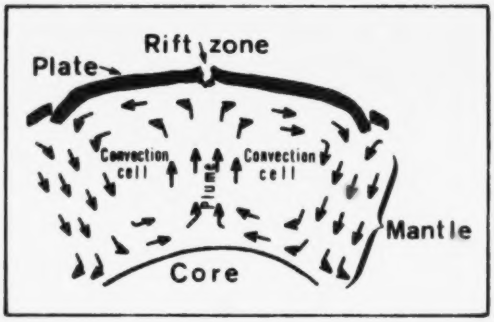


Figure 11.3. This is a diagram of convection cells within the mantle. The arrows in the mantle point the direction of flow. Plumes occur under continental and oceanic plates.

III. Volcanic products: Liquids, solids, and gases are all erupted from volcanoes. Their proportions can vary in different volcanoes and, from time to time, in the same volcano.

A. Gases: From 5 to 8 percent of magma is trapped gases. The activity of gases in a volcano frequently determines how violent a volcano will become. If the gases can escape with ease, the eruption will most likely be subdued. However, trapped gases (those unable to escape) create violent explosions. At the highest temperatures of the eruption, 1,100° to 1,200° Centigrade (2,000° to 2,200°F), some of the gases exist as elements. However, when they cool, they combine to produce several different compounds.

1. Water vapor: Water vapor constitutes about 70 percent by volume of the gases in magma and is the main volatile. It escapes from volcanoes in the form of steam. It is believed that our present atmosphere formed from gases delivered

to the earth's surface by volcanoes. In the same process, water vapor condensed to accumulate in low-lying areas. Because of the huge quantities, there was a sufficient amount of water to form oceans and to establish a water cycle.

2. Carbon dioxide: This is the second most abundant volcanic gas, 14 percent by volume. Frequently, carbon dioxide combines with water to form carbonic acid (which is important in the weathering of rocks).
3. Sulfurous gases: These perfumed delights are most easily noted because of their odor (that of rotten eggs). Most often, they are present in the form of molecular sulfur (S_2), sulfur dioxide (SO_2), and hydrogen sulfide (H_2S).

B. Trace elements: There are small traces of other elements that often occur as simple compounds. These include nitrogen, argon, boron, chlorine, and fluorine. Metallic elements include copper, iron, mercury, and zinc. These are of special interest because their presence has been noted in many ore deposits that formed in the last stages of igneous activity.

C. Lava: Lava is the most abundant material that volcanoes erupt. Hot lava resembles hot tar; cooler lava resembles thick honey. Its composition can vary.

1. Silica: All lava contains at least 45 percent silica, or technically speaking, silicon dioxide, but there are important variations. If the lava is of mafic composition (that is, rich in iron and magnesium), it cools less rapidly, allowing gases to escape more easily. The gases then form bubbles, or vesicles, in the resulting rock. If it is richer in silica, or felsic, it is thicker and will harden more rapidly, preventing the easy escape of gases. Many times, trapped gases explode in attempt to escape.
2. Oxides: Also present are oxides of aluminum, iron, calcium, sodium, potassium, and magnesium.

D. Rock types: These are simply solidified lava. Again, the type depends upon the silica content.

1. Basalt: Basalt is the most abundant of all volcanic materials. It is dark in color; is one-half silica; and is highest in calcium, magnesium, and iron oxides. Because of its lower silica content, basaltic volcanoes are rarely explosive.
2. Scoria: A variety of basaltic lava that commonly has a porous, rough texture due to the rapid cooling of the lava near the surface of the flow.
3. Rhyolite: Rhyolite is three-fourths silica and is light in color. Its high silica content is responsible for explosive eruptions.
4. Andesite: Andesite is two-thirds silica and medium in color. These rocks are also high in sodium and/or potassium. Eruptions of andesite are frequently explosive. Andesites are common along the continental margins near subduction zones.
5. Obsidian: Obsidian is a volcanic glass. It has the chemical composition of felsic rock, but when it was erupted, it cooled so quickly that crystals did not have time to form. Pumice is a glassy rock with the same composition as obsidian, but it contains many small holes.
6. Pumice: Pumice is a porous volcanic glass. It occurs when a rapid expansion of gases takes place in a felsic lava, causing a "foamy" texture to be created.
7. Tuff and breccia: When air borne fragments (See VI A.4.) of volcanic ash are deposited and consolidated, the rock is known as tuff. Breccia is formed when larger volcanic fragments (1/4 inch to 2 inches) are deposited and cemented together.

IV. Intrusive or plutonic features: If magma fails to reach the earth's surface, it remains under a great deal of pressure. In an attempt to move to areas of less pressure, it may squeeze its way into, around, or through existing rock before cooling. Those structures formed below the earth's surface from the cooling magma are called intrusive or plutonic features. (See Figure 11.4) The rocks composing intrusive features usually have larger crystal development because they cooled slowly.

  A. Types of structure: No doubt for simplicity (?), intrusive structures have cooperated by forming in one of two ways that allow them to be easily classified.

    1. Concordant structures: If magma positions itself parallel to the surrounding layers of rock, it forms a concordant structure.

      a) Sill: A sill is a horizontal sheet of magma that has solidified between layers of sedimentary rock. Sills can range in thickness from a few meters to hundreds of meters. The Palisades in New Jersey, along the banks of the Hudson River, provide viewing of one of the best-known sills.

      b) Laccolith: A laccolith is similar to a sill but larger. It is dome-shaped with a flat floor, and it causes overlying material to arch upward. A laccolith may range in size from relatively small to many kilometers in area. The central mass of the Henry Mountains in Utah is a laccolith.

    2. Discordant structures: These are composed of igneous rock that cuts across the surrounding layers of rock.

      a) Dike: A dike is an almost vertical wall of rock that cuts across adjacent rocks. It is found that most dikes occupy cracks in the crust and are much longer than they are wide. An interesting example of a dike can be found at the West Spanish Peaks in Colorado, where the dikes radiate outward like an old volcano.

      b) Batholith: This is a huge chamber of solidified magma that can extend over an area of up to thousands of square kilometers. It is believed that the Sierra Nevada Mountains in California are a batholith that was uplifted and tilted millions of years ago.

      c) Stock: This is a mini-batholith that is less than 100 square kilometers (40 mi^2).

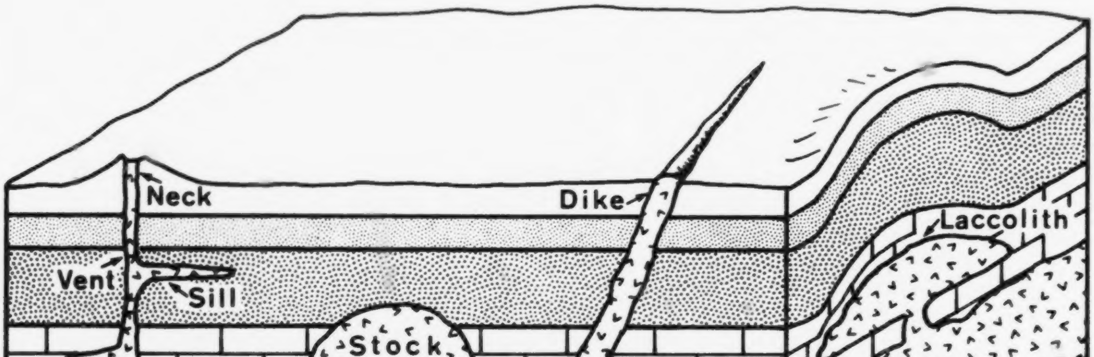


Figure 11.4. Intrusive structures are shown in this block diagram.

B. Types of rocks: The following are common examples of intrusive rocks.

1. Granite: Granite dominates intrusive rock types with the largest percentage of area in the deeper levels of large land masses. Its light color is the result of its composition of large amounts of silicon, sodium, and potassium.
2. Diorite: The texture of granite and diorite is nearly the same. However, diorite contains calcium rather than sodium, resulting in a darker color.
3. Gabbro: The coarse grained intrusive equivalent of basalt. It is composed primarily of plagioclase felspar and ferromagnesium minerals. Gabbro is not very common in the United States but is abundant in Labrador and in Finland.
4. Peridotite: This very dark rock is composed primarily of the mineral olivine. It is rather rare, but is important in the study of the earth's interior. Peridotite forms in the upper mantle of the earth and travels upward toward the surface with basaltic lavas.

V. Extrusive or volcanic structures: If magma does reach the surface of the earth, it does so by moving through a pathway of least resistance. Because of this, zones of fractured rock provide an ideal exit for magma. Those features formed by lava on the earth's surface are called extrusive or volcanic structures. Rocks creating these structures cooled quickly and are therefore fine-grained or glassy. The creation of these structures can take mere hours to many years. The creation can also take place all at once or intermittently over a long period of years.

A. Volcanic cones: Magma reaches the earth's surface by way of a "pipeline" called a vent. Volcanic debris forms a cone-shaped protrusion on the earth's surface called, of all things, a volcanic cone. There are several land forms that can be constructed by volcanic action.

1. Cinder cone: This type of cone has steep slopes of approximately 30 degrees and a large crater (a depression directly above the vent that feeds the volcano). This cone is rarely over 366 meters (1,200 ft) high. (See Figure 11.5) Cinder cones are composed entirely of fragments of volcanic rock ejected from the vent (called pyroclastic material or tephra) and form with the largest and densest fragments falling closest to the vent. The rock fragments are mainly basalt or andesite. Some well-known examples include Paricutin in Mexico, Amboy Crater in California, and Mauna Kea in Hawaii.

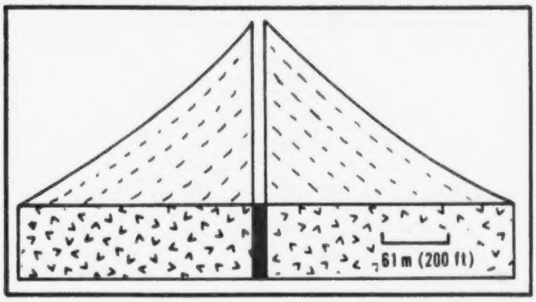


Figure 11.5. A cinder cone is composed of pyroclastic material that built up around the vent. The dashed lines indicate pyroclastic material; the v's are pre-volcanic rock.

Occasionally, new vents open up to produce another cone built on the flanks or in the crater of a cone. This is called a parasitic cone, and while it frequently occurs on cinder cones, it also appears on other cones. (See Figure 11.6) Paricutin is a parasitic cone on the flanks of a cinder cone in Mexico. Novarupta in Alaska is a parasitic cone on Katmai.

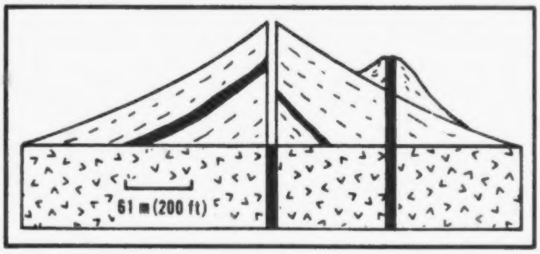


Figure 11.6. The small cone on the right is a parasitic cone. The solid black is lava.

2. Shield cone: Quiet eruptions are typical of this type of cone, built entirely of lava flows. Mafic in composition, the lava is very mobile at the time of eruption creating a cone with broad sides and a slope of only a few degrees. (See Figure 11.7) Some of the world's largest volcanoes are shield cones with an average diameter of about five to seven kilometers (3 to 4 mi) and a height of 450 to 600 meters (1,500 to 2,000 ft). Mauna Loa in Hawaii is a shield cone. It is also the largest volcano in size in the world, measuring 9.6 kilometers (6 mi) in height. The portion above sea level measures 96 kilometers (60 mi) in length and 48 kilometers (30 mi) in width.

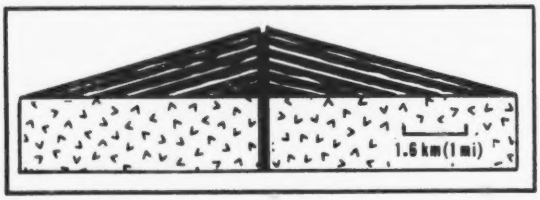


Figure 11.7. A shield cone is composed of lava flows.

3. Composite cone: This volcanic cone combines explosive eruptions with the outpouring of lava to produce a cone built of alternating layers of lava and pyroclastic materials. (See Figure 11.8) It is larger than a cinder cone but not so steep-sided. It is normally about 1,800 to 2,400 meters (6,000 to 8,000 ft) above its base. The composition is mainly andesite. Nearly all large active volcanoes of the world are of the composite type. Familiar examples include Mount Vesuvius in Italy, Mount Fuji in Japan, Mount Shasta in California, and Mount Rainier in Washington.

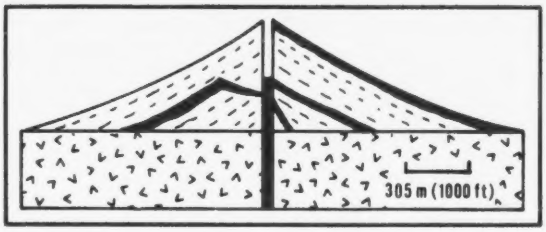


Figure 11.8. A composite cone is composed of a combination of lava and pyroclastic material.

B. Volcanic dome: Quieter volcanic activity is responsible for a dome. It is constructed by the eruption of great blobs of viscous, pasty lava rich in silica that were too cool to flow easily. Nearly circular and rounded, domes can be formed within a crater or on the flanks of a cone (as a parasitic cone) during the waning phase of volcanism. (See Figure 11.9) Examples include Lassen Peak and Mono Crater in California, Novarupta Dome in Alaska, Showa-Shinzan Dome in Japan, and Mount Pelee in West Indies.

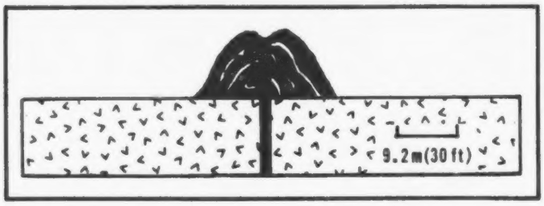


Figure 11.9. A volcanic dome is composed of blobs of pasty lava.

C. Lava plateau: Sometimes, long cracks in the earth called fissures allow magma to make its exit onto the earth's surface. A lava plateau (also known as flood basalt) is a relatively flat area on the earth that has been covered by a series of lava flows. (See Figure 11.10) These flows may cover large areas and be as thick as 610 meters (2,000 ft). Examples include the lava fields in Iceland and the Columbia River Plateau in northwestern United States.

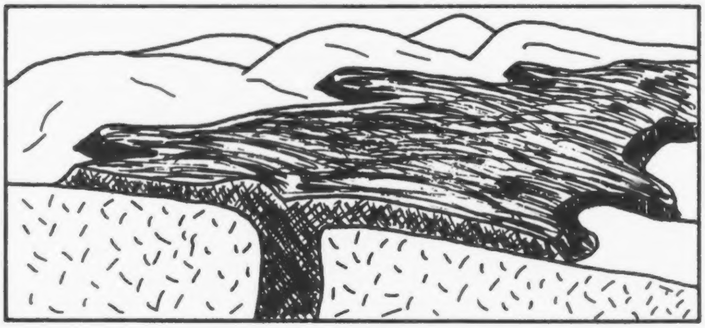


Figure 11.10. Lava sometimes flows out of fissures to cover large areas creating lava plateaus. Thousands of years can lapse between flows.

VI. Features in volcanic rocks: As lavas cool rapidly, a variety of features are "frozen" into the volcanic rocks. Strongly influencing these features are such characteristics as the chemical composition, the water and gas content, and the rate of cooling.

A. Smaller-scale products: While lava can cover a considerable area, hand-size specimens can display typical characteristics of the various kinds of lava.

1. Aa (ah'ah) lava: This Hawaiian word describes a crumbly, uneven lava that forms when the surface cools rapidly. Vesicles (or holes) in the lava are formed when the gases escape. (See Figure 11.11)

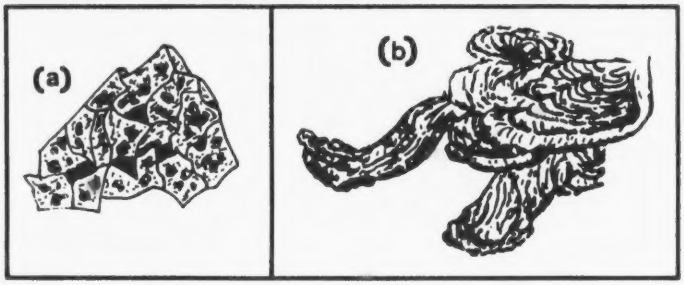


Figure 11.11. (a) is aa lava, and (b) is pahoehoe lava.

2. Pahoehoe (pah-hoay-hoay) lava: Chemically identical to aa, pahoehoe had a smooth, ropy surface that cooled more or less evenly. (See Figure 11.11) When lava contains gases, it flows more easily, remains liquid longer, and creates pahoehoe. The ropy surface is the result of the hardening of a thin crust while lava in a liquid state flows below the crust. There appears to be a different combination of gas and heat, allowing for the differences between aa and pahoehoe.

3. Pillow lava: This rare lava forms when a lava flow meets water and cools instantly. The rapid cooling causes the lava to subdivide into ellipsoid or circular bodies resembling (surprise!) pillows. Pillow lavas are most common near rift zones where new ocean floor is being created at divergent plate boundaries.

4. Pyroclastics: As defined earlier, pyroclastics are fragments of volcanic rock ejected from the vent. They can form through various means and are not necessarily of the same composition. One form of pyroclastics is volcanic bombs, which are spindle-shaped chunks that are produced when molten lava is ejected through the air to be rapidly cooled. They assume streamlined shapes while in flight. (See Figure 11.12) Volcanic ash, another pyroclastic, forms when lava shoots into the air, and gases inside the lava expand rapidly to shatter the lava into fragments. When the ash settles on the ground, it is known as tuff. If the ash contains large pieces, it is known as volcanic breccia.

B. Larger-scale products: Larger-scale products add some interesting creations to the landscape.

1. Lava tunnels: As lava that is highly charged with gas flows, the surface and walls will harden, forming a tunnel. The molten lava underneath may continue to flow without abundant heat loss. If the flowing lava drains out of the tunnel, a hollow tube (or lava tunnel) remains. (See Figure 11.13) Examples are those in Hawaii, the Lava Beds National Monument in Siskyou County, California, Craters of the Moon in Idaho, and Hot Creek Valley in Shasta County, California. These have become great tourist attractions.

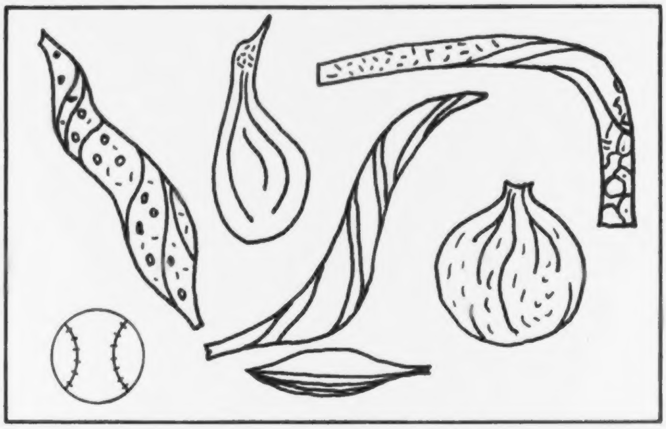


Figure 11.12. Several varieties of lava bombs. (The baseball is for scale.)

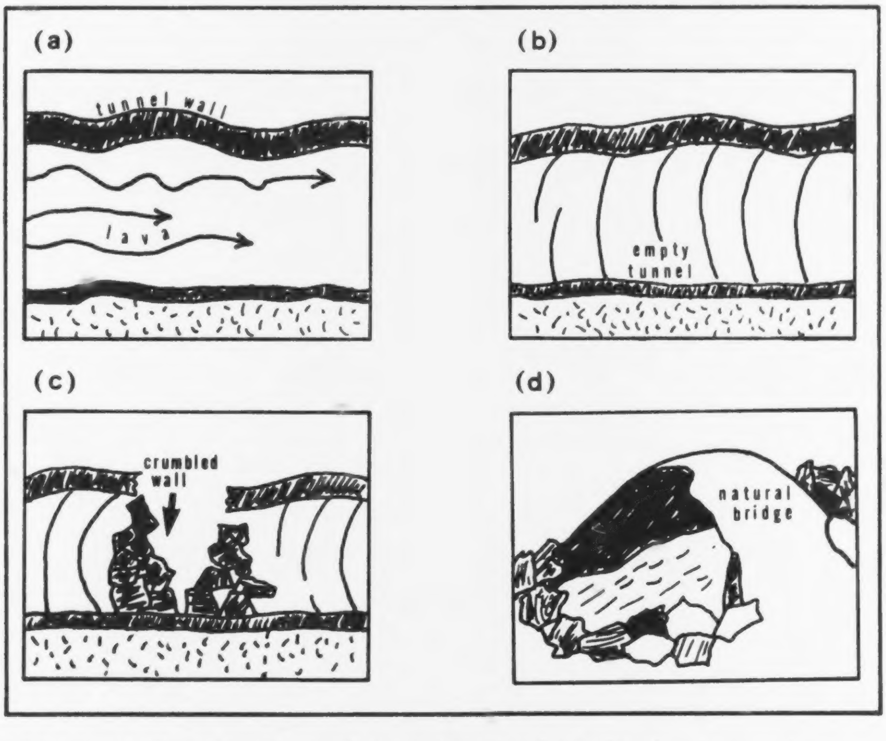

(a)
tunnel wall
lava
(b)
empty
tunnel
(c)
crumbled
wall
(d)
natural
bridge

Figure 11.13. (a) illustrates the surface and walls of the flowing lava as it cools; (b) shows the draining of the lava, leaving a hollow tube; (c) represents the hardened lava of the tunnel after it weakens and falls to expose the lava tunnel; (d) pictures a natural bridge formed when most of the roof falls in. (Nat. Park Ser.)

2. Columnar joints: Joints, as they are described here, are cracks that appear in more or less regular patterns. As lava cools, it sometimes contracts about centers, forming four- to six-sided patterns. The length of the column is always at right angles to the top and bottom of the flow. (See Figure 11.14) Devil's Postpile National Monument in Andesite, California, and Devil's Tower in Wyoming display excellent examples of columnar jointing. (Why the name Devil, do you think?)

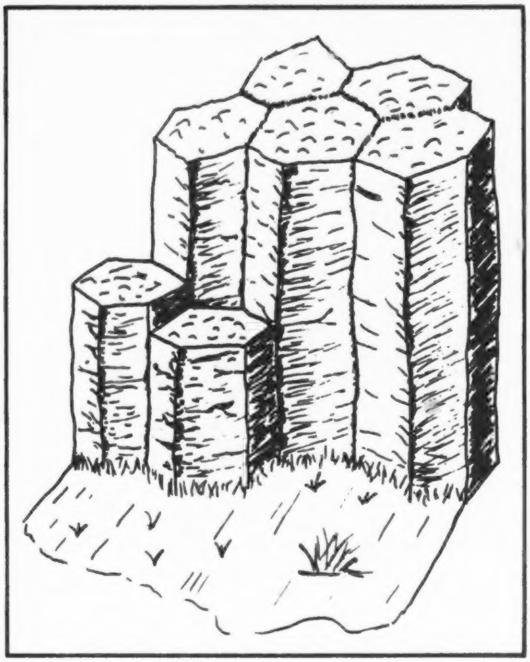


Figure 11.14. A section through a lava flow showing columnar joints caused by contraction during cooling.

VII. Life cycle: As soon as lava is laid to rest, it is at the mercy of the elements (so to speak)--wind, water, ice, and gravity. These agents of erosion (the moving of sediment from one place to another) create a change of landforms. Any changes are influenced, however, by the volcano's stage of activity.

A. Stages of activity: Within the life cycle of a volcano, there appear to be three stages of activity--active, dormant, and extinct. Among experts, there is no complete agreement as to the exact span of time and the meaning involved in each of those terms. For our purpose, we will generalize (and let the experts argue among themselves!). It is hard to definitely classify a volcano. No doubt, the residents of Pompeii and Herculaneum, in 79 A.D., thought Monte Somma was extinct. Yet that year, Mount Vesuvius had its birth, and the nearby residents had their death.

1. Active: A volcano which has erupted in recent years or has a history of eruptions over the last several hundred years.
2. Dormant: A rather vague term applied to volcanoes that have not erupted in recent times, (whatever that means) but evidence does exist that the area is still volcanically active and future eruptions are possible.
3. Extinct: In this stage, not only hasn't the volcano erupted in hundreds of years; but there is no evidence of any volcanic activity in the region. In fact, in most cases, erosion has removed much of the original volcanic cone leaving only a neck or plug of very hard lava that was once the main vent. Shiprock, New Mexico is an excellent example of an extinct volcanic cone.

B. Local volcanism: Local volcanism concerns the erosion of a volcanic cone.

1. Stages of erosion: When volcanic activity ceases, erosion begins its job of dissecting the volcanic cone. Until this time, the cone is relatively symmetrical. Streams begin to cut furrows creating a radial pattern of drainage; that is, the streams radiate outward from a central point, the vent. When the furrows are deep, the dissection is considered to be at an intermediate or mature stage of development. A volcanic neck is a mass of volcanic material that hardened in the vent. In the final stage of dissection, all that remains of the volcanic cone is the volcanic neck and possibly exposed dikes. (See Figure 11.15) They are more resistant to erosion because they are composed of a harder rock; they remain long after the volcanic cone has eroded away.

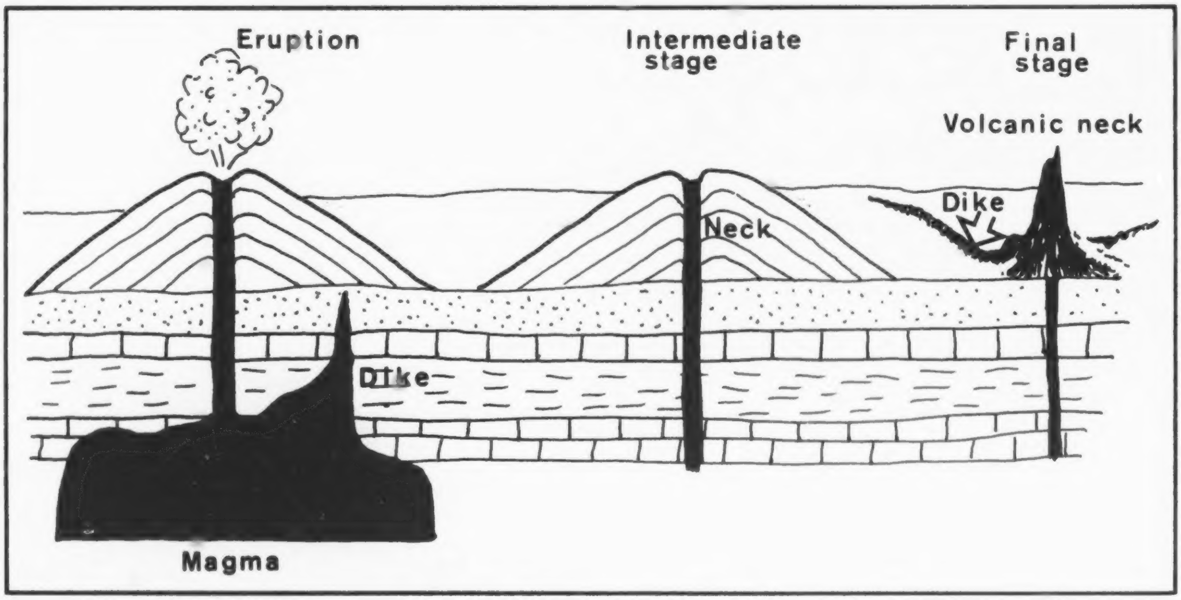


Figure 11.15. When a volcano becomes dormant, it is subject to immediate erosion. Magma in the vent hardens and is less subject to erosion than the soft surrounding material of the cone. Eventually, the harder neck and dikes are exposed.

2. Caldera: Influencing the life cycle of a volcano as just described is a caldera. A caldera is a large volcanic depression with a diameter several times larger than a crater (typically several kilometers across). It can be formed two ways. Of the two ways, the results are similar. There can be huge, explosive eruptions causing a collapse from withdrawal or material in the vent. It is also possible to create the same effect when magma cools and shrinks allowing a progressive collapse of the rim of the crater. (See Figure 11.16) Crater Lake in Oregon is one of the world's most famous calderas.

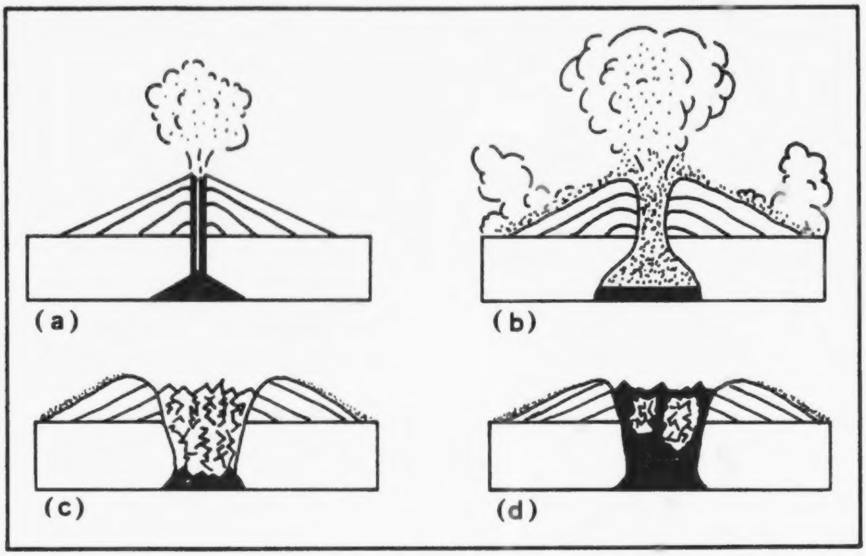


Figure 11.16. A collapse caldera occurs in the following sequence: (a) is a mild explosion of pumice; (b) is a violent explosion, part of which is pyroclastic material thrown in the air and part of which is a glowing cloud of ash and dust; (c) is the collapse of the top of the cone thus forming the caldera; (d) is renewed volcanic activity.

C. Regional volcanism: In regions of lava plateaus, erosion attacks the landscape in a different manner than that of a volcanic cone. As lava floods an area, streams are displaced to the margins of the field of lava, and new ones form across the plateau. When lava no longer extrudes into the area, the streams begin to actively erode the lava plateau and the surrounding area. This is considered the intermediate stage of dissection. In the final stage, the lava plateau has been eroded away leaving a lowland with remnants of lava as a cap rock (a layer of resistant rock on top of other rock). (See Figure 11.17) Eventually, even these erode away.

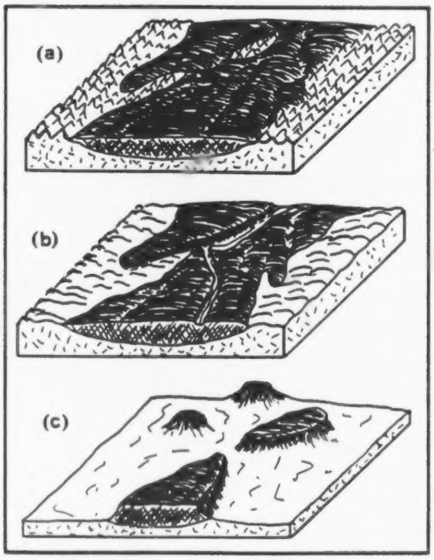


Figure 11.17. The life cycle of a lava plateau occurs in the following sequence: (a) is the early stage after lava has flooded a large area; (b) is the intermediate stage after streams have started to dissect the lava plateau, and the rock around the plateau has undergone a great deal of erosion; (c) is the last stage in which only remnants of lava cap rock remain, and the surrounding area has been leveled by erosion.

D. Volcanic aftermath: Upon the decline of volcanism, volcanic gases (including water vapor) may take over to create some interesting and oftentimes beautiful features. The features are also subject to change in response to earthquakes altering the subsurface. Post-volcanic creations can all be seen in Yellowstone National Park.

1. Fumaroles: These are vents from which gases are erupted. The source is from an underground channel system reaching down to the hot rock masses where there is very little groundwater. The small amount of water that is present is instantly converted to steam and shot through the vent. Solfataras are fumaroles from which only sulfurous gases are emitted.
2. Hot springs: Hot springs result from the quiet discharge of water that flows more or less continuously. Many hot springs are popular for their advertised therapeutic value.

Jellystone National Park
Old Faceful

3. Geysers: From the Icelandic word meaning "to rush furiously," a geyser is a type of hot spring that erupts occasionally to form a fountain. (See Figure 11.18) Old Faithful is a classic example. Rainwater seeps underground and is heated by deeply buried hot rocks. Temperatures of 204° Centigrade (400°F) or higher are attained because of high underground pressures. The hot water and steam rise toward the surface through cracks or fissures where the pressures are lower. The pressure of steam bubbles is too great to quietly escape, so instead, the steam lifts the water out of the vent.

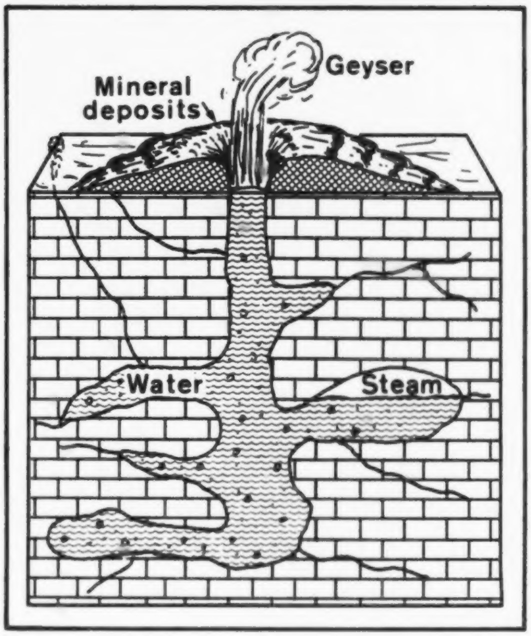


Figure 11.18. A block diagram of a geyser shows the super-heating of groundwater in cavities, causing periodic eruptions.

4. Associated phenomena: In rocks near hot springs and geysers, more can be seen than just hot water. This is one reason for the great tourist attraction to areas such as Yellowstone National Park. Iron compounds formed by chemical reactions of rocks and water result in water and rocks around hot springs and geysers being red, yellow, or brown. In other areas, algae turn the water other colors such as green or blue. Volcanic ash or tuff is altered by hot water into clay, primarily. As gases escape in basins of clay, an appearance of luscious (?), bubbling, boiling mud is achieved. In other areas, calcium carbonate and silica are dissolved by hot water. Upon reaching the earth's surface, they are then deposited as cones, domes, terraces, and other unusual shapes.

VIII. Destructive volcanoes in recorded history: Ever since people have had the mobility to see the vastly different terrains of the earth, they have been attracted by the fertile soils and beauty of volcanic areas. Unfortunately, their attempts to live near volcanoes are the reason volcanoes are so dangerous. Would a volcano be considered dangerous if there were no people nearby? Table 11.1 lists some of the most destructive volcanoes in recorded history.

IX. Coexistence--people and volcanoes: As with life, there is bad and good to be gained from volcanoes. In beholding the good, people tend to ignore the bad. However, if society is on top of the situation (figuratively speaking!), it must measure the options before deciding to live with the threat of eruption.

A. Hazards: A hazard is a possible exposure to danger. Volcanic hazards result in property damage and loss of life.

1. Lava flow: A lava flow can come from the crater or the flanks of a cone. It usually moves slowly enough (a few meters per hour) that a person could outrun it. There are exceptions, though, when it flows several kilometers per hour. Sometimes, it is possible to temporarily divert the flow, but as yet, it cannot be stopped. Lava flows are especially hazardous in Hawaii.

Table 11.1. Destructive volcanoes in recorded history.

Volcano	Location	Known Start of Activity	Rate of Activity	Known Casualties	Cause of Deaths
Stromboli	Sicily	Pre-600 BC	More or less continuous	?	Lava
Vesuvius	Italy, Bay of Naples	Quiet for centuries before 63 AD	More or less continuous since 63 AD	Thousands	Lava
Santorin	Between Greece and Turkey	Pre-2500 BC	Violent off and on since 2500 BC	Thousands, especially from 2500 to 1200 BC	?
Hekla	Iceland	18 eruptions since 1100 AD	Regular	?	?
Pelée	Martinique, Lesser Antilles	?	Irregularly violent	30,000	Gases
Etna	Sicily	Pre-Homer, pre-900 BC	More or less continuous	Thousands, 20,000 in 1669	?
Krakatoa	Indonesia, Sunda Strait	1680 and earlier	Irregularly violent	Thousands, 36,000 in 1883	Most from tsunami

2. Mudflow: Volcanic ash, dust, and larger fragments found on the slopes of a volcano become saturated with water from rainfall or melting snow. Mudflows usually occur during the rainy season following volcanic eruption. However, melting glacial ice produces some biggies. The Osceola mudflow at Mount Rainier that occurred 5,000 years ago was the largest that was ever recorded. It flowed 64 kilometers (40 mi) down valley and spread over 168 square kilometers (65 mi^2) at a thickness of 21 meters (70 ft). Mudflows are most potentially hazardous to areas similar to the Cascades in northern California.
3. Heavy "rainfall" of ash and dust: Solid rock and pumice may be ejected into the air in great volumes and travel in the atmosphere for thousands of kilometers. Falling ash is blinding, choking, and poisonous. It reduces visibility, kills vegetation, contaminates water, blocks pipes, and overloads roofs. In 1973, the volcano Eldfell on the island of Heimaey, in Iceland, produced a classic ash eruption.
4. Suffocating gases: Poisonous gases such as sulfur dioxide, carbon monoxide, and hydrochloric acid can kill life for many miles around the base of a volcano. Some gases are heavier than air and settle at lower levels where only shorter people (reminds me of a song) and smaller animals are affected. In the Eldfell eruption, the only human casualty was a man who went into a cellar where poisonous gases had settled.
5. Nuee ardente (glowing cloud): Incandescent particles of ash and dust are expelled from a volcano and quickly mix with hot gases. This mass is heavier than air and flows down slopes rapidly. It is known as a nuee ardente. A nuee ardente appeared after the 1902 eruption of Mount Pelee, swept down across the city of St. Pierre, and killed 30,000 people. One person survived, a man who was a prisoner in an underground dungeon. He was later released from the crimes for which he had been imprisoned.

B. Benefits: A benefit produces an advantage or improvement. Without the benefits of volcanoes, this earth would be a very different and much less habitable place in which to live.

1. Fertile soil: Quickly in humid areas, volcanic rocks weather to produce very fertile soil, rich in mineral elements. Winds also spread volcanic ash over thousands of square kilometers adding to soil fertility. The Columbia Plateau in northwestern United States is very productive, agriculturally. Idaho potatoes would never be the same without volcanic soils. Mount Vesuvius has vineyards planted on its flanks.
2. Water vapor: Without water from volcanoes, we would be all dried up, folks! Volcanoes have provided nearly all of the water upon the earth and in the atmosphere.
3. Carbon dioxide: Carbon dioxide makes possible the survival and evolution of plants.
4. Volcanic rock: Volcanic rock provides decorative building stone. Crushed, it is an excellent foundation material for roads and airfields. Pumice and ash are good abrasives. Tuff, a fine material, is easily put into sacks and used later in building.

5. Geothermal energy: Geothermal energy is heat from the earth's interior. Geysers and hot springs are a source of energy, provided the market is nearby. Iceland has used natural hot water for heating homes and greenhouses since 1925. More sophisticated production of geothermal electricity in Iceland began in 1964. In addition, this type of power is being used in California, New Zealand, and Italy. Solutions to the problem of clogged pipes associated with geothermal power are now being sought.

6. Beauty: There is a need for beauty in this world, and volcanoes can help contribute to this cause. A World's Fair location was chosen in Seattle, Washington, with Mount Rainier as a backdrop.
7. Ore deposits: Many of the world's high-grade deposits of copper, zinc, lead, silver, and gold are associated with ancient volcanic rocks or with present-day volcanic island arcs along plate boundaries.

C. Prediction: Apparently, the benefits of living in a volcanic area outweigh the hazards, because people still choose to do so. It is therefore necessary to become as scientifically knowledgeable as possible in the prediction of eruptions. Hawaii (the Hawaiian Volcano Observatory on Kilauea), Iceland, and the Mediterranean area are the world's greatest volcano laboratories because of their locations in the volcanic activity belt. (See Figure 11.19) Several prediction clues have become evident.

1. Increase in tilt: As magma rises, there is a slight increase in the tilt of the slope of the cone. This tilt can be measured by tiltmeters. (Where have you heard this before?)
2. Minor earthquakes: There is an increasing frequency of minor earthquake shocks, measured by seismographs. These sometimes begin months in advance of the eruption.

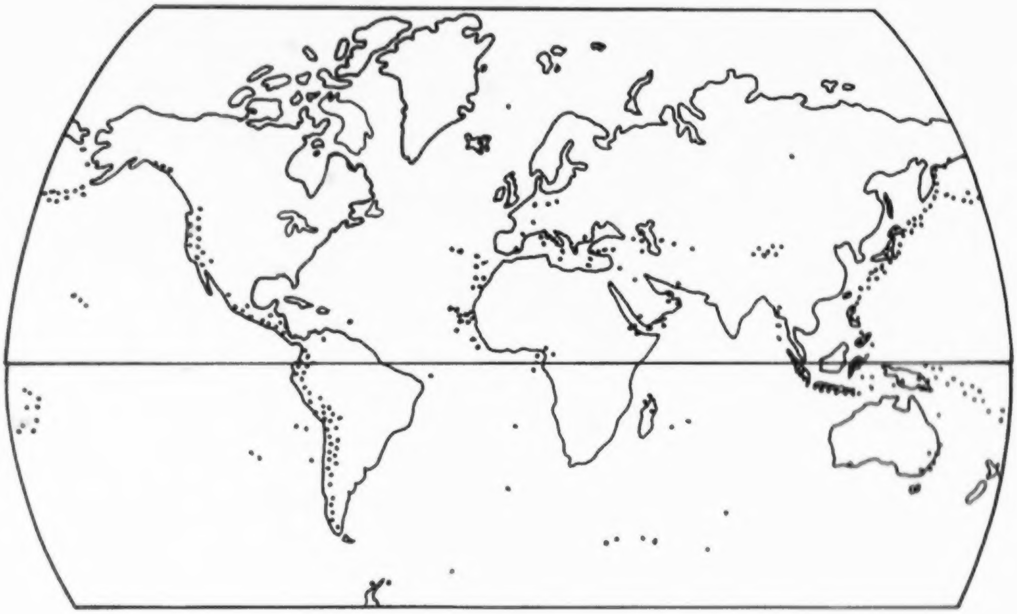


Figure 11.19. The world distribution of volcanoes is indicated by dots.

3. Increasing temperatures: As magma rises, it also increases temperatures above and below the ground. Through fissures or drillholes, the increasing temperatures can be measured a short time before an eruption.
4. Increase in subcrustal noise: As magma is making its big move underground, the move is not done on tiptoes; thus, the noise can sometimes be heard.

5. Magnetic changes: Before a volcanic eruption, magnetic changes occur, but no correlation between these changes and the length of time before an eruption has been established.

X. Summary: As eruptions of magma are spewed over the earth's surface, they deliver a number of products--gases, lava, and rocks which may then form several structures. Most obvious are volcanic cones in the shape of cinder cones, composite cones, shield cones, or volcanic domes. Covering broader areas are lava plateaus. If magma fails to reach the earth's surface, it may harden in the shape of sills, laccoliths, dikes, batholiths, or stocks. Very surprising are the varieties of features resulting if the same magma that hardened into intrusive structures had experienced extrusion. Aa, pahoehoe, and pillow lava, in addition to various pyroclastics, hold little resemblance to the same material composing, for instance, a sill. The same is true for a larger-scale product, a lava tunnel. Once volcanic activity has reached its last stage, the bubbling and gurgling of lava may be replaced by that of water or possibly volcanic mud. They come in possible forms of fumaroles, hot springs, or geysers. Volcanoes have succeeded in abruptly eliminating any life nearby through lava flows, mudflows, heavy "rainfalls" of ash and dust, suffocating gases, and nuee ardentes. On the other hand, they have blessed us with fertile soils, water vapor, carbon dioxide, volcanic rock, geothermal power potential, beauty, and ore deposits. As with earthquakes, reliable prediction of all volcanic eruptions is still in the future. Amidst their hazards, they are one of the natural wonders of the earth, and they provide clues to the earth's past and future.

SEE ACTIVITY 11.1

SEE ACTIVITY 11.2

Chapter 11: Problems and Questions

1. How do magma and lava differ?
2. Relate the occurrences of volcanoes to plate boundaries.
3. Discuss the various products of a volcanic eruption, and tell how they influence the type of eruption.
4. Compare and contrast the size, shape, and composition of the four (4) types of volcanic cones.
5. Describe the basic intrusive igneous structures.
6. Discuss the two (2) ways a caldera can form.
7. Compare and contrast the origin and structure of a volcanic cone and a lava plateau.
8. Discuss the effect of the rate of cooling on the characteristics of lava.
9. Briefly describe the ideal erosion cycle of a volcanic cone.
10. Briefly describe the erosion cycle of a lava plateau.
11. Describe how geysers, fumaroles, and hot springs are related to volcanism.
12. Discuss the possible hazards resulting from volcanic eruptions.
13. Describe the benefits from volcanoes. List another benefit not given in the text.
14. Discuss the detection measures being used to predict volcanic eruptions.

Unit IV: Internal Processes

CHAPTER 12: Mountains

- I. Introduction
- II. Structural Forces Which Create Mountains
  - A. Folding
    - 1. Parts of a Fold
      - a) Axis
      - b) Limbs
      - c) Crest
      - d) Trough
    - 2. Types of Folds
      - a) Symmetrical Folds
      - b) Asymmetrical Fold
      - c) Overturned Fold
      - d) Plunging Fold
    - 3. Structural Folds
      - a) Anticline
      - b) Plunging Anticline
      - c) Dome
      - d) Syncline
      - e) Plunging Syncline
      - f) Basin
      - g) Monocline
  - B. Faulting
    - 1. Parts of a Fault
      - a) Hanging Wall
      - b) Footwall
      - c) Fault Scarp
      - d) Fault Line
      - e) Slip
      - f) Fault Zone
    - 2. Types of Faults
      - a) Normal or Gravity Fault
      - b) Reverse Fault
      - c) Thrust Fault
      - d) Strike-slip or Lateral-motion Fault
- III. Basic Mountain Types
  - A. Folded Mountains
    - 1. Origins
    - 2. Effects of Erosion
  - B. Fault-block Mountains
    - 1. Origins
    - 2. Effects of Erosion
  - C. Dome Mountains
    - 1. Origins
    - 2. Effects of Erosion

You think you've got problems, wait until I get to the edge of this page!

- D. Volcanic Mountains
    - 1. Origins
    - 2. Effects of Erosion
- E. Complex Mountains
    - 1. Origins
    - 2. Effects of Erosion
- F. Residual Mountains

IV. Major Mountain Ranges of the World
- A. North America
- B. South America
- C. Asia
- D. Africa
- E. Europe
- F. Australia
- G. Antarctica

V. Mountains of the Future

VI. Mountains and People
- A. Travel
- B. Military Significance
- C. Economy
- D. Climate
- E. Recreation

VII. Summary

Related Activities

Vocabulary

Add strike and dip symbols to various folded structural features.

Form modeling clay into various structures that create mountains.

Identify evidence of crustal movement on topographic maps and aerial photos.

Predict future mountain ranges or alteration in existing ones based on present plate movement.

Plot major mountain ranges on a world map.

Problems and questions

Mountain Geo Facts

The Andes Mountains in South America extend in an unbroken chain from the Caribbean Sea to the Straits of Magellan at the southern tip of South America.

The highest submarine mountain is in the Tonga Trench between Samoa and New Zealand. It rises 8,693 meters (28,500 ft) from the ocean bottom, and its top is still 366 meters (1,200 ft) below the surface of the water.

Chapter 12: Word List

Anticlinal valley
Anticline
Asymmetrical fold
Axis
Basin
Complex mountains
Crest
Cuesta
Diastrophism
Dip
Dome
Fault
Fault-block mountains
Faulting
Fault line
Fault scarp
Fault zone
Flatiron
Folded mountains
Folded rock
Footwall
Geosyncline
Graben
Hanging wall
Hogback
Horst
Joint
Limb
Monocline
Mountain
Normal or gravity fault
Offset drainage
Overturned fold
Plunging fold
Ravine
Residual mountains
Reverse fault
Ridge
Slip
Strike
Strike-slip fault
Symmetrical fold
Synclinal ridge
Syncline
Thrust fault
Through

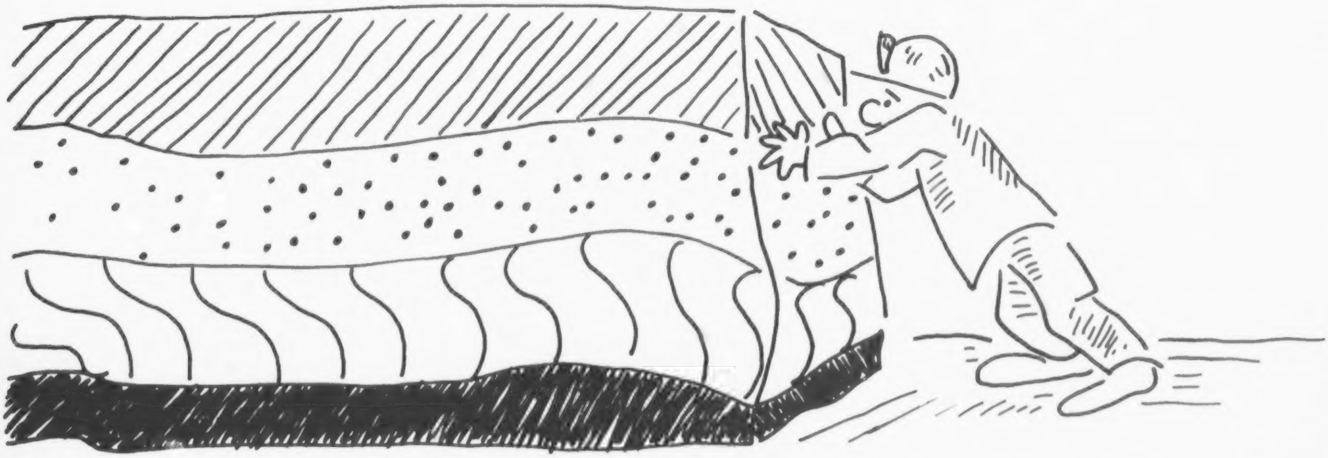
Straight Terms

Asset
Asymmetric
Breach
Buckle (v.)
Diagonal
Elliptical
Facet
Flank
Intersection
Lateral
Metamorphosed
Organic
Symmetric
Warp

Chapter 12: Mountains

I. Introduction: A mountain is any elevated area that is underlain by rocks that are structurally disturbed or by rocks of volcanic origin. A mountain may range in size from a few hundred meters to several thousand meters high. Primitive people believed that mountains were separate worlds, the home of the gods. The classical Greeks solemnly respected the mountains, believing they were created by the pull of the stars. In Biblical times, mountains maintained their importance, because it was from them that God frequently spoke. Once again, science has taken away much of the mystery surrounding the origin of the mountains, but they are still respected as some of the most wondrous places on earth. In this chapter, you will study the different kinds of mountains created by diastrophism (a process or the processes by which the crust of the earth is deformed.)

II. Structural forces which create mountains: Until this time, you have studied many features that are easily observed, for example, the eruption of a volcano. This chapter deals with much more guesswork about origins, simply because most of the forces that create mountains are so slow that they cannot easily be observed. As rocks undergo various forces, they respond by either breaking or bending or both, depending upon the kind of rock, the depth of rock, the temperature, and the pressure.



A. Folding: Folded rocks are simply rocks that have bent. Because rocks farther down in the crust are warmer and are under greater pressure, they tend to bend rather than break when opposing forces push the rock layers into a smaller area. When describing the direction and angle the rocks are resting, strike and dip are used. Strike is the directional trend of the outcrop on a level surface. Dip is the compass direction that the rock layer is sloping, while angle of dip is the number of degrees the layer slopes from the horizontal. Strike and dip direction are always 90 degrees apart. (See Figure 12.1)

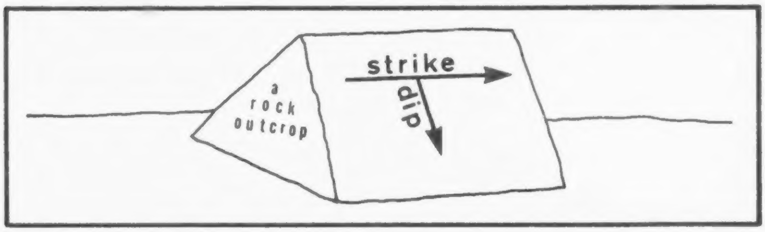


Figure 12.1. An illustration of strike and dip.

1. Parts of a fold: In order to understand the parts of a fold being discussed, each part has been named. (See Figure 12.2)
   a) Axis: This is the line that divides the fold in two as equally as possible. An axial plane is a plane that goes through the axis at an angle such that the limbs are almost symmetrical on each side of it.
   b) Limbs: These are the sides of the fold.
   c) Crest: This is a line across the highest part of the fold. It is sometimes the same as the axis.
   d) Trough: This is a line across the lowest part of the fold.

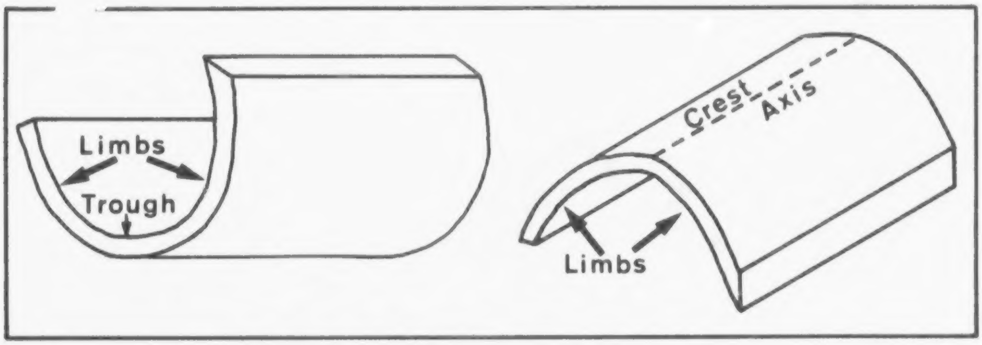


Figure 12.2. Shows the various parts of the fold. In this illustration, the crest and the axis are the same, although this is not always the case.

2. Types of Folds: There are several different shapes into which forces may fold rocks.

a) Symmetrical fold: This is one in which the limbs look exactly alike on each side of the axis. (See Figure 12.3) This type of fold results from the same amount of force pushing in on each side of the fold.

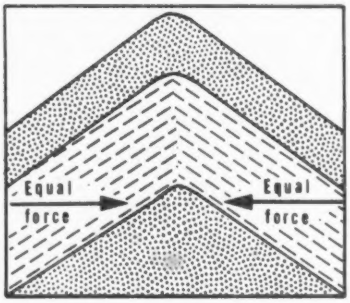


Figure 12.3. A cross-section of a symmetrical fold. Note that the forces causing the rock to bend are equal on each side.

b) Asymmetrical fold: This is a lopsided fold, formed as a result of more force from one side of the axis than from the other side. (See Figure 12.4)

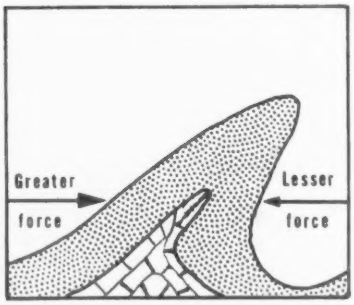


Figure 12.4. A cross-section of an asymmetrical fold.

c) Overturned fold: An overturned fold is one in which both limbs dip in the same direction making the fold appear as though it is on its side. (See Figure 12.5)

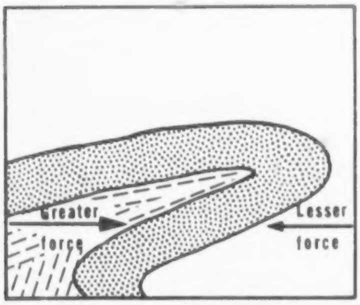


Figure 12.5. A cross-section of an overturned fold.

d) Plunging fold: This is a fold in which the axis is not horizontal; instead, it tips in one direction because of unequal forces. (See Figure 12.6) A plunging fold is much more typical than a fold with a horizontal crest because of the variety of the forces forming it. After it has undergone erosion, it is easily recognizable from above, because it resembles a canoe.

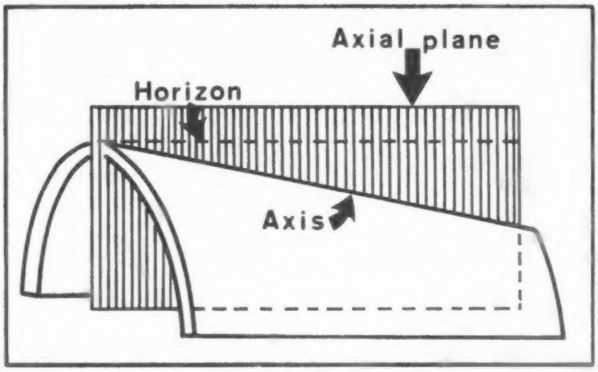


Figure 12.6. An illustration of a plunging fold. Note that the axis is at an angle to the horizon.

3. Structural folds: With different combinations of force, rock type, heat, and pressure, rocks may bend to form a variety of structures.
   a) Anticline: This is an upward fold; the oldest rocks are in the center, and the beds dip away from the axis. (See Figure 12.7) An anticline can range in size from a small-scale bend you may see in a roadcut to a huge anticline like the one creating the Ural mountains, which separate Europe from Asia. The state of Florida is formed by a long, low anticline with a northwest to southeast axis. Because of their structure, anticlines are good traps for oil. Oil accumulates in a porous rock such as sandstone. If an impermeable rock layer such as shale covers the sandstone, the oil is trapped. (See Figure 12.8)

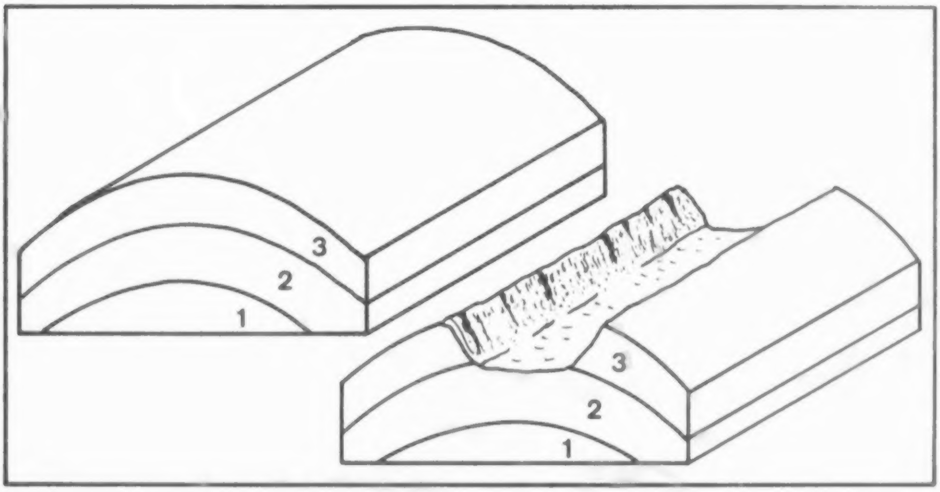


Figure 12.7. An illustration of an anticline before and after erosion. The beds are numbered so that the larger the number, the younger the rock layer.

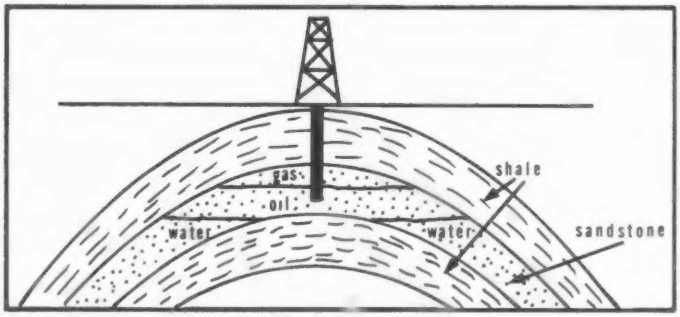


Figure 12.8. Oil is trapped in the sandstone layer of this anticline. The shale layer above it, in combination with the anticline structure, traps the oil and makes it easier to withdraw from the ground.

b) Plunging anticline: This is simply an anticline with an axis that is not horizontal. (See Figure 12.9)

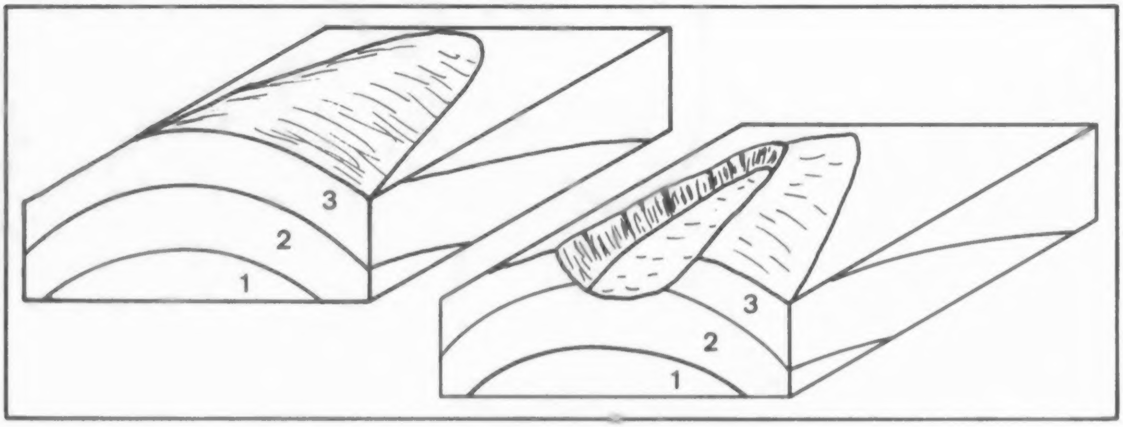


Figure 12.9. An illustration of a plunging anticline before and after erosion.

c) Dome: This is an anticline in which the beds dip or plunge outward in all directions from a central point. (See Figure 12.10) A dome is not formed as a result of horizontal forces but is due rather to broader-scale vertical movements, something down below the rock layers such as magma pushing up. The Black Hills, of South Dakota, are a dome.

d) Syncline: This is a downward fold; the youngest rocks are in the center, and the beds dip or plunge toward the axis. (See Figure 12.11) Again, the syncline size can range from small to huge as exemplified in the San Joaquin Valley in California (also known as the Great Valley of California).

e) Plunging syncline: The axis of a plunging syncline is not horizontal; thus a syncline becomes a plunging one. (See Figure 12.12)

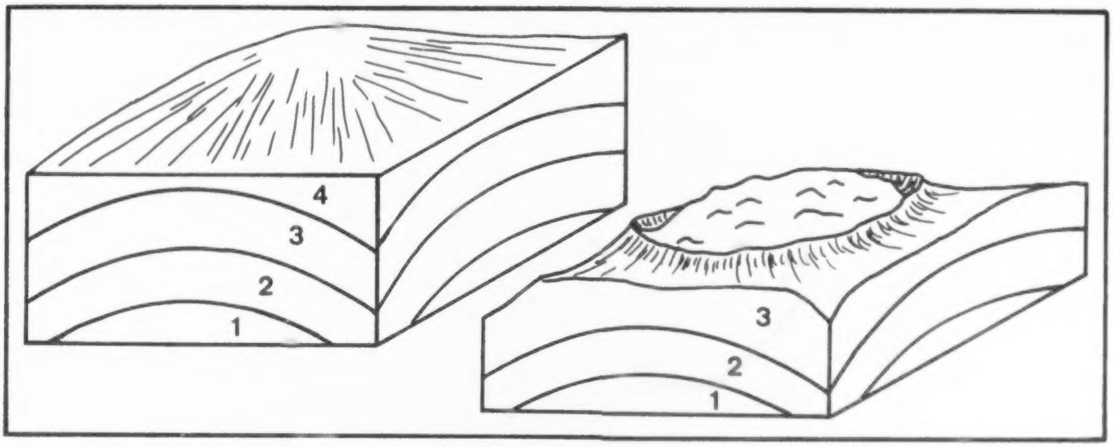


Figure 12.10. An illustration of a dome before and after erosion.

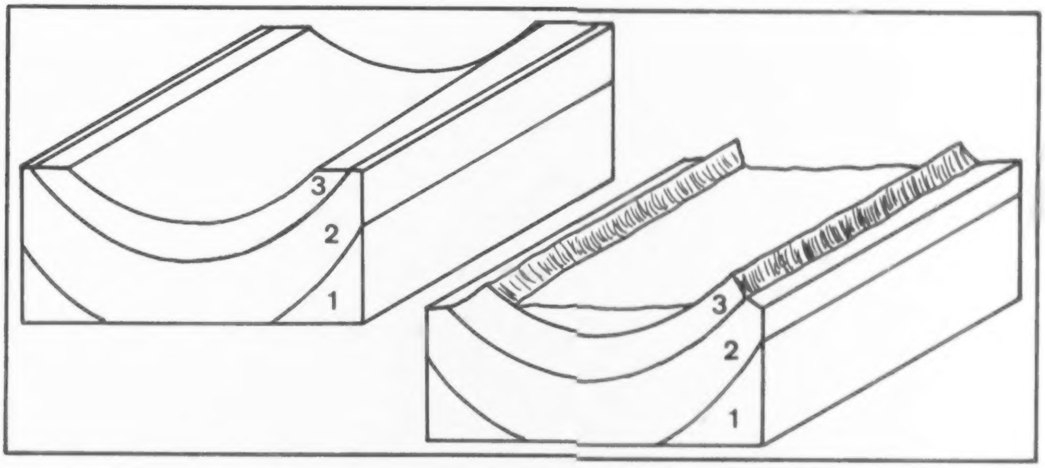


Figure 12.11. An illustration of a syncline before and after erosion.

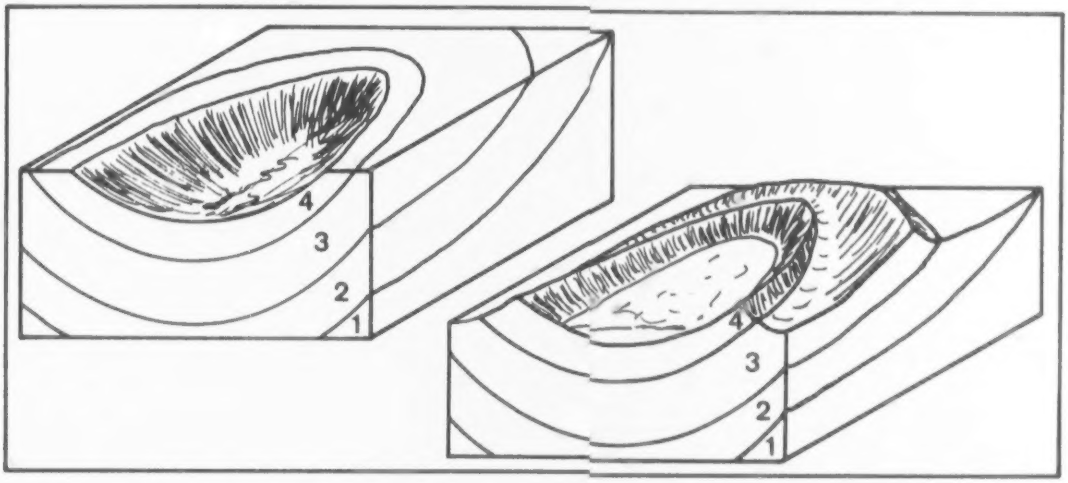


Figure 12.12. An illustration of a plunging syncline before and after erosion.

f) Basin: The opposite of a dome, a basin is a syncline with the beds dipping inward from all directions to a central point. (See Figure 12.13) A basin may be the result of the weight of accumulating sediment causing a downwarping. Illinois and Michigan are examples of structural basins.

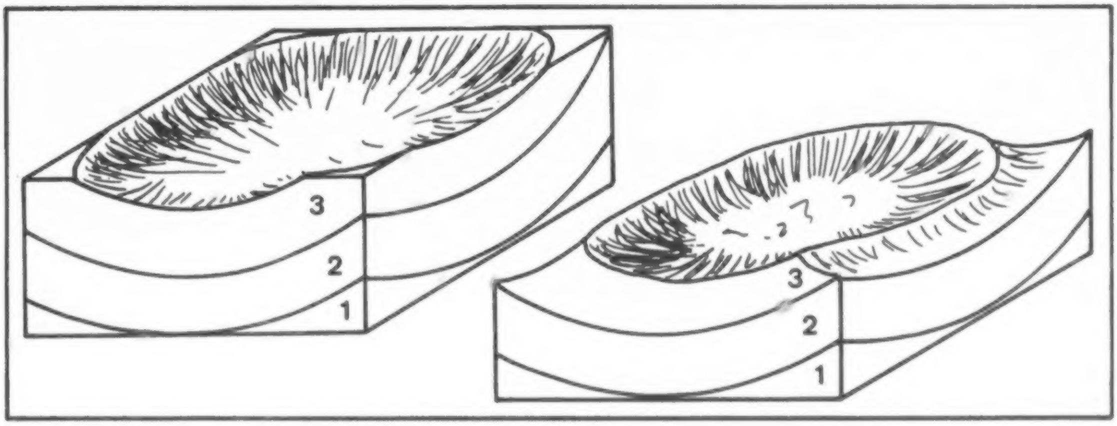


Figure 12.13. A basin before and after erosion.

g) Monocline: This is a structure that resembles one limb or bend of an anticline or syncline. This kind of fold may turn into a fault at greater depth. (See Figure 12.14) An example of a monocline can be found on the Colorado Plateau.

h) Homocline: If only the dipping portion of the monocline is exposed, or if the rock structure has only a single, sloping dip the structure is known as a homocline.

SEE ACTIVITY 12.1

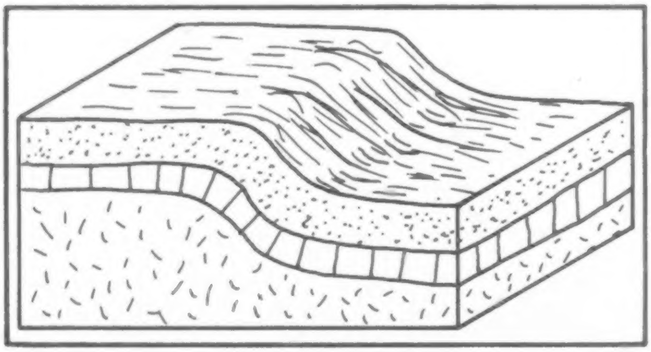


Figure 12.14. An illustration of a monocline.

B. Faulting: As you recall, a fault is a crack in crustal rocks along which movement takes place when one side of the bedrock slips or moves relative to the other side. However, it must be pointed out that both sides do not have to move. Faulting (the rock movement along a fault) is more common at the surface of the crust, because rocks near the surface are cooler and thus more brittle.

1. Parts of a fault: In order to understand faulting jargon, the following terms must also be understood. (See Figure 12.15)
    - a) Hanging wall: Hanging wall is an Old English mining term. To understand it, one must project a mine tunnel into a fault, as seen in Figure 12.15. Picture yourself standing on the mine floor. With the plane of the fault going diagonally across the mine tunnel, the hanging wall is the mine ceiling and one wall.
    - b) Footwall: Placing yourself again in the Old English mine (Do Not Enter Mine Without Safety Helmet!), the footwall is the floor of the mine and the remaining sidewall.
    - c) Fault scarp: This is an abrupt cliff produced directly by faulting. It is subject to immediate erosion.
    - d) Fault line: This is the intersection of the fault with the surface of the earth.
    - e) Slip: This is the amount of displacement or the amount of movement that was made to create the fault.
    - f) Fault zone: Instead of the straight plane along which two blocks of earth moved, there may be a zone of movement hundreds to thousands of meters wide that consists of ground up rock or of many small, interconnected faults.

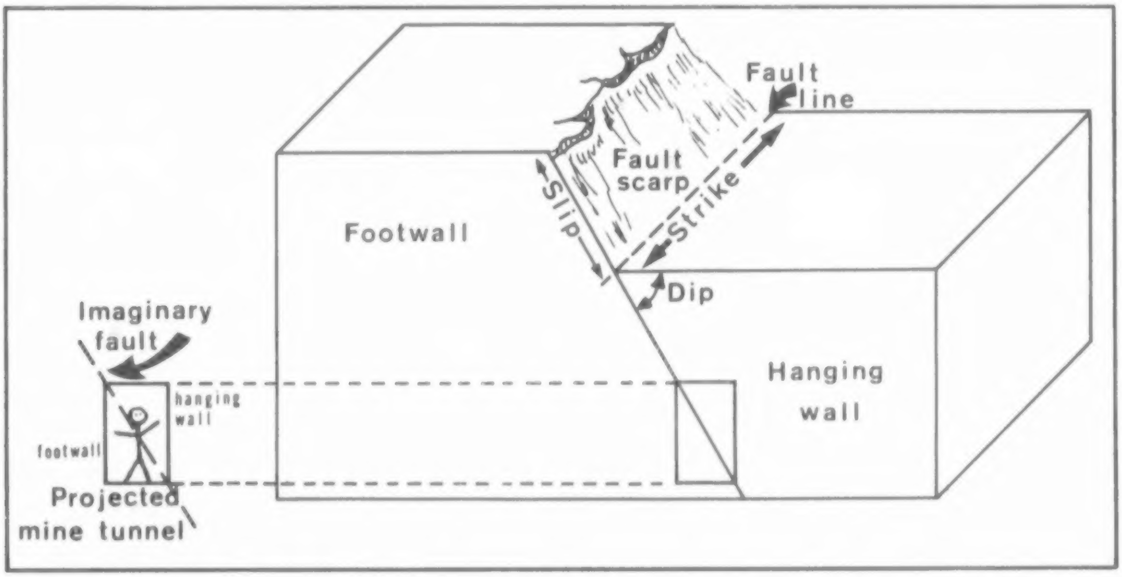
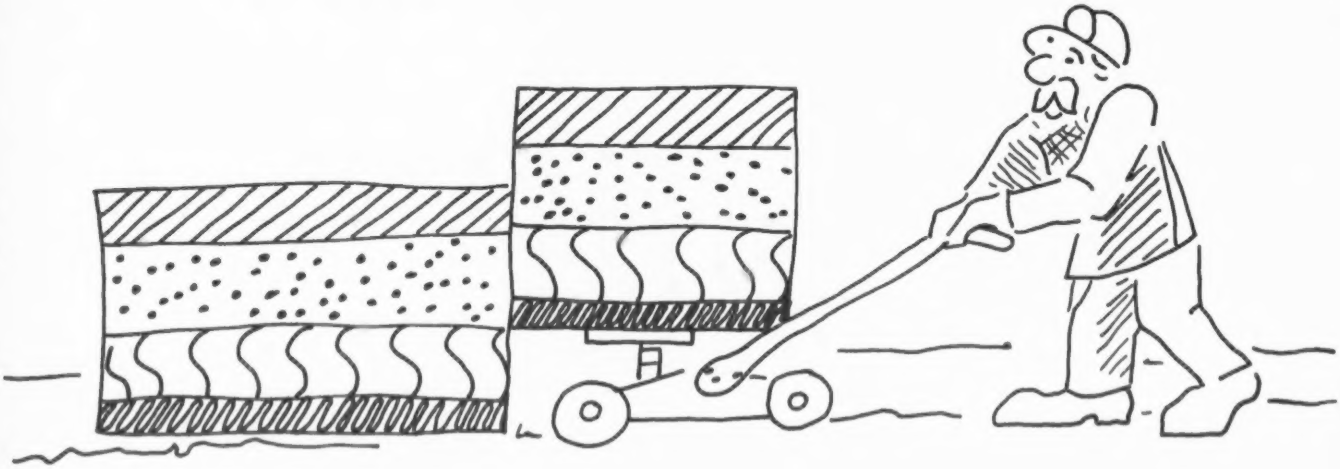


Figure 12.15. A block diagram of a faulted area. The various parts of a fault are labeled. One small area of the fault is projected to the left as a mining tunnel to aid in the understanding footwall and hanging wall.

2. Types of faults: The forces causing crustal movements are varied, and so the creations from these forces are also varied. Sometimes, they may begin with a joint (a crack or break in the rock along which no crustal movement has occurred).



a) Normal or gravity fault: The hanging wall has moved down relative to the footwall in a normal fault. (See Figure 12.16) The term normal is poor because normal faults are not more common than other faults. When they were originally named, it was believed that they were more common. Scientific knowledge corrected the misconception but not the name. The Teton Mountains of Wyoming are an example of high-angle normal faulting.

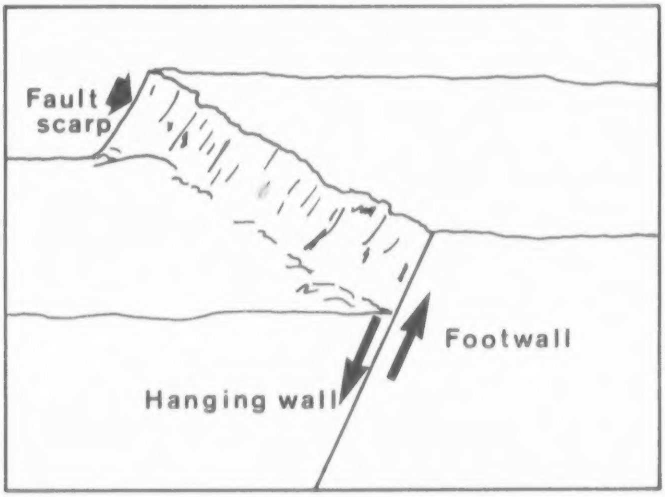


Figure 12.16. An illustration of a normal fault. The arrows show the direction of the crustal movement.

b) Reverse or thrust fault: In this type of fault, the hanging wall has moved up relative to the footwall. (See Figure 12.17) The fault scarp produced by this type of fault would tend to form an overhanging cliff. However, the heavy overhanging rock soon falls, giving the fault scarp the surface appearance of a normal fault scarp.

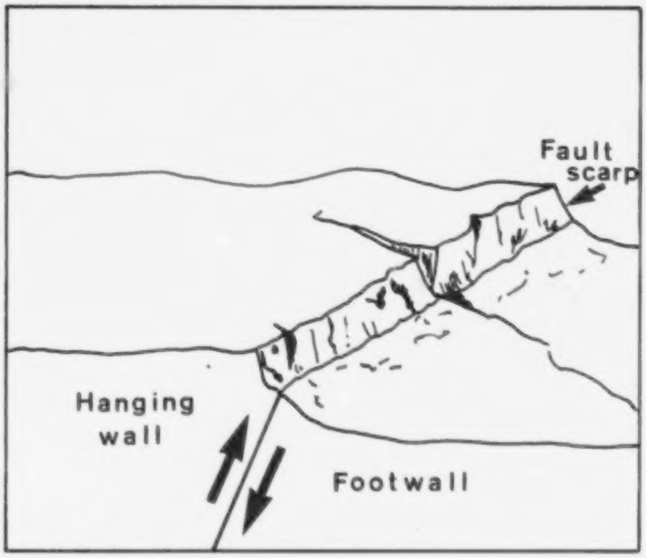


Figure 12.17. An illustration of a reverse fault.

c) Thrust or overthrust fault: A thrust fault is a reverse fault in which the hanging wall is at a low angle to the horizon. The movement has been mainly horizontal. (See Figure 12.18) The fault scarp is less obvious than with other fault types. It is believed that some thrust faults may be the result of gravity, with the hanging wall sliding off a higher area. Thrust faulting seems to occur more frequently in areas of extreme folding where opposing forces are greater. An example of thrust faulting is seen at Chief Mountain in Montana.

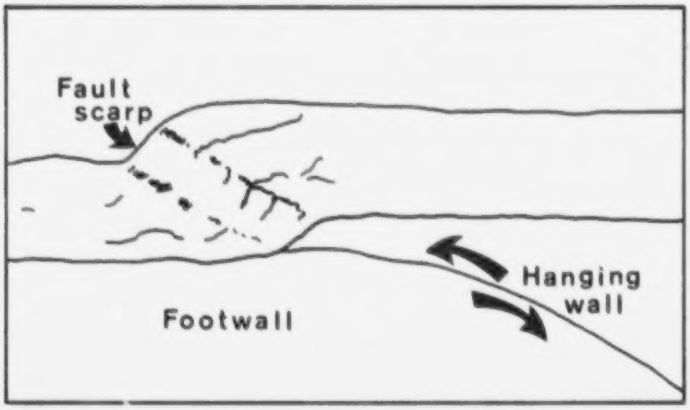


Figure 12.18. When a low-angle reverse fault occurs, it is known as a thrust fault.

d) Strike-slip or lateral-motion fault: In this type of fault, the movement has been horizontal. The fault- blocks simply slide by each other horizontally. (See Figure 12.19) The San Andreas fault zone represents this type of faulting. It is recognized at the surface by small scarps, offset drainage (a nearly right-angled displacement of a stream), small wedge-shaped hills, and ponds.

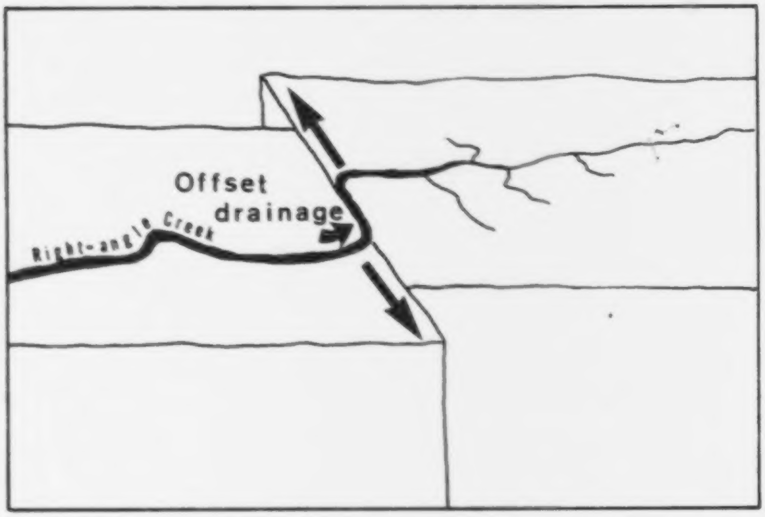


Figure 12.19. An illustration of a strike-slip fault. Notice how the stream follows the fault line for a short distance illustrating offset drainage.

III. Basic mountain types: Until the theory of plate tectonics was proposed, there was no single theory of mountain building that could explain all of the structural features that were observed. Now, within the framework of plate tectonics, it is possible to explain those forces of mountain building. The geosynclinal theory is an excellent example of this situation. A geosyncline is a long, broad trough that borders a continent. It is a dumping ground for vast volumes of sediment that has eroded from the continent, in addition to organic remains of ocean life. The theory includes the following process: The sediment turns to rock, having accumulated to depths of kilometers; lateral forces begin pushing; rocks at depths are metamorphosed; faulting allows magma to seep up from the mantle to the crust, possibly forming some volcanoes; in the meantime, there is uplift, and the geosyncline becomes a mountain range. The only detail lacking in this theory was a cause or force. Now, the plate tectonics theory provides us with an explanation of how a trough can become a mountain range--simply because one plate collides with another, forcing the geosynclinal deposits upward. Thus, convergent plate boundaries are the sites of major fold-belt mountains and in addition, island arcs. (See Figure 12.20) With this overview of mountain building in mind, each type of mountain will be considered individually.

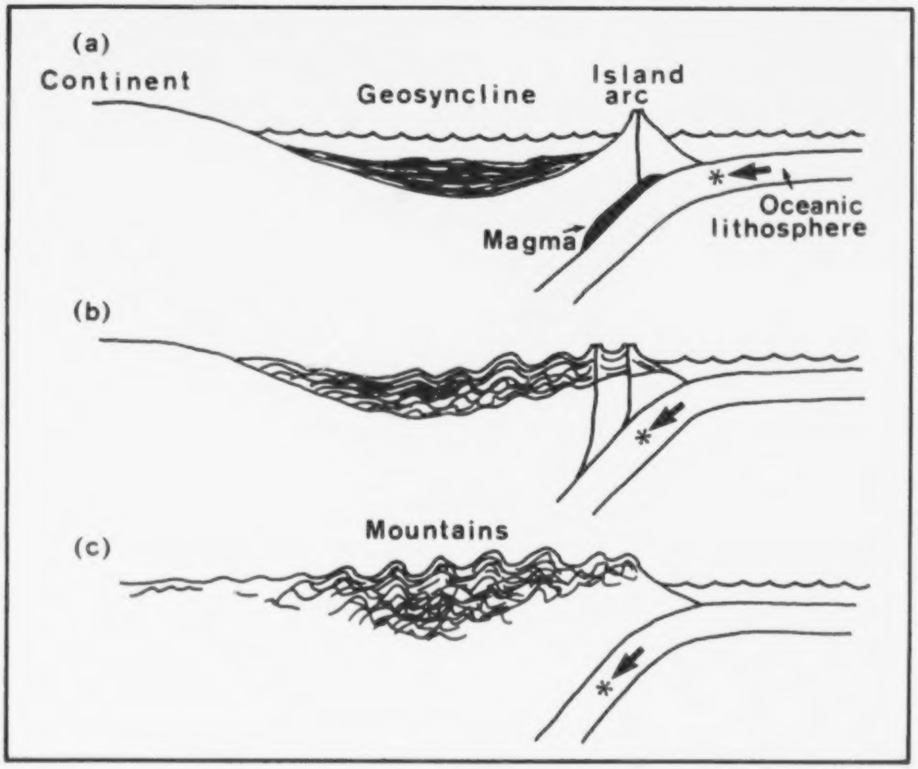

(a)
Continent
Geosyncline
Island arc
Magma
Oceanic lithosphere
(b)
Mountains
(c)

Figure 12.20. (a) shows sediment deposited in shallow seas along the margin of the continent; (b) illustrates how lateral forces begin to deform the deposits; (c) shows how sedimentary deposits are shoved up into a folded mountain belt. The star on the oceanic plate enables you to get an idea of the amount of plate movement.

A. Folded mountains: Folded mountains are simply a series of anticlines and synclines similar in form to that of a wrinkled rug. (See Figure 12.21) A good example is the older Appalachians which were reduced from 800 kilometers to 432 (500 to 270 mi).

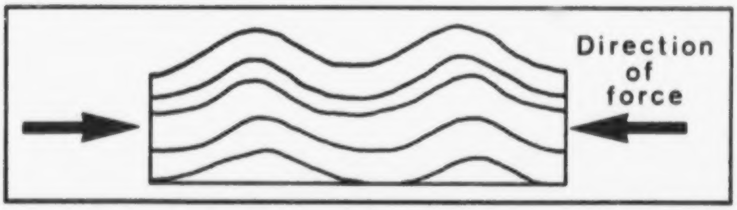

Direction of force

Figure 12.21. A cross-section of folded mountains. The arrows indicate the direction of force caused by plate movement.

1. Origin: Folded mountains are formed by the buckling or warping of rocks that have experienced stress over a long period of time. The rocks originated in a geosyncline that was pushed upward when two plates collided. The Appalachians formed in this manner when the African, European, and North American plates collided.
2. Effects of erosion: Erosion tends to attack the anticlinal portion of the folded mountain more rapidly because these rocks are weakened from being uplifted, and they are exposed to more erosive agents at their higher elevation. Thus, they can be leveled quickly in geologic time. It is important to remember that an anticline is a deformed structure and after time, may not necessarily remain a ridge (a long, narrow elevation of land) as a result of erosion. Erosion will flatten it, but the structure still exists beneath the eroded surface. Sometimes, the crests or tops of anticlines will yield to erosion in such a way that narrow valleys will form along the mountain top. These high valleys are known as anticlinal valleys. (See Figure 12.22) The anticlinal valleys continue to get longer and deeper until the anticline is completely cut open along the entire length of the crest. On the flanks of the anticline, resistant rock forms ridges which are known as hogbacks. Erosion continues to flatten the anticline until it is lower in level than the synclinal valley (the synclinal trough). Because the once-synclinal valley is now higher in elevation than the anticline, it becomes a synclinal ridge--long, narrow, and flat-topped.

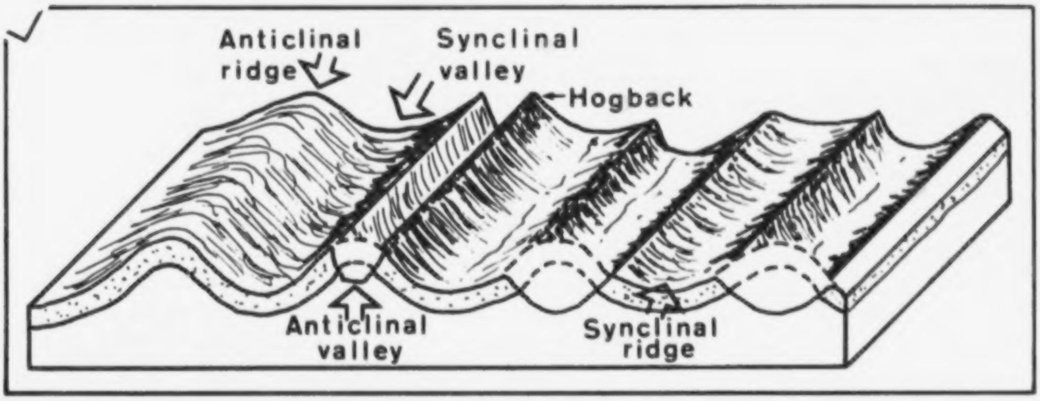


Figure 12.22. This is an idealized diagram showing the possible aftermath of anticlines and synclines once they have undergone some erosion. The dashed lines indicate the previous location of rock.

If the axes of the folds are not horizontal, plunging anticlines and synclines are formed. They erode to create zigzag ridges. (See Figure 12.23) In eastern Pennsylvania, some good examples of zigzag ridges can be found.

B. Fault-block mountains: These involve faulted blocks of earth that are large-scale in size, some hundreds of kilometers long and tens of kilometers wide. (See Figure 12.24) The Sierra Nevada Range, in California, is a fault-block mountain range. Most fault-block mountains are very irregular and rugged in appearance. They are frequently recognized as a tilted block of earth with a steep fault scarp and a gentle back slope (the side of a ridge that has less slope).

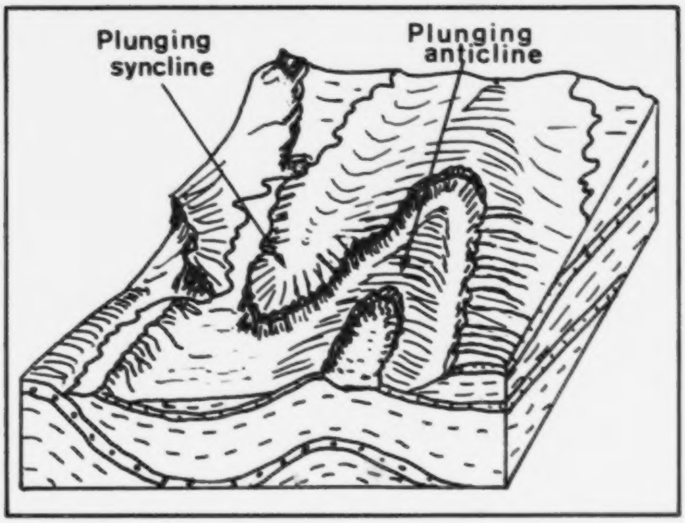


Figure 12.23. Zigzag ridges form after the erosion of plunging anticlines and synclines.

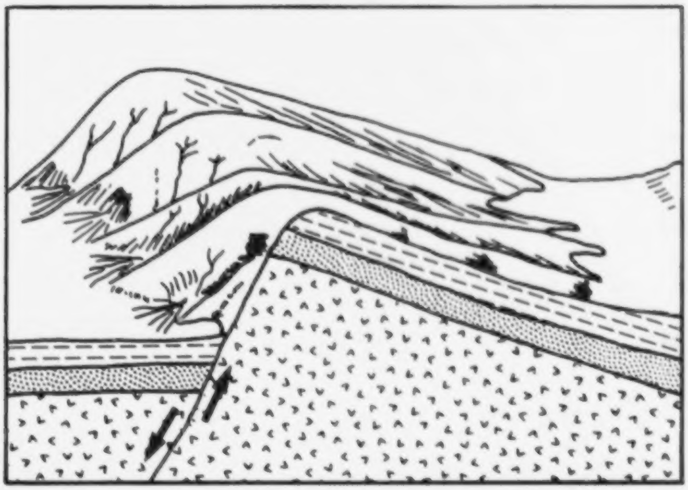


Figure 12.24. An illustration of a fault-block mountain.

When there are more or less parallel faults, blocks of the earth's crust may be raised or lowered between these faults. The raised blocks are horsts, and the lowered blocks are grabens. (See Figure 12.25) Grabens are very irregular in shape because the scarps are cut by deep canyons, and the valley floors contain a large amount of sediment. Those that are deep and fairly new make dramatic scenery, as seen in Death Valley. Lake Tahoe, bordering California and Nevada, is located in a graben. The Ruby-East Humbolt Range in Nevada is a horst.

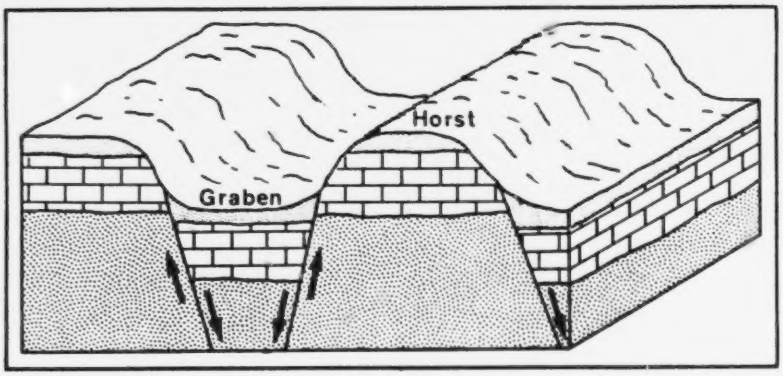


Figure 12.25. An illustration of horsts and grabens (sounds like something you eat on rye bread).

1. Origin: Fault-block mountains are the result of quickly applied stress that breaks rather than bends the rocks. They are often closely associated with folded ranges and volcanoes. This provides you with a clue to their origin--that is, colliding plates. An example is our Sierra Nevadas formed by the North American plate sliding over the eastern Pacific plate.
2. Effects of erosion: In young mountains, the fault line tends to be straight and easily recognized. As the mountains age, V-shaped ravines (steep-sided trenches formed by running water) develop on the fault scarp, and gradually the original surface of the scarp is removed. The V's begin to meet at the top of the scarp, thereby carving triangular facets, sometimes known as flatirons. (See Figure 12.26) The V's continue to widen until the triangular facets become difficult to recognize. The remainder of the scarp is destroyed, and the base of the cliff moves backward as it is consumed by erosion. The rugged appearance of the mountains softens to gentle hills and then to low ruin.

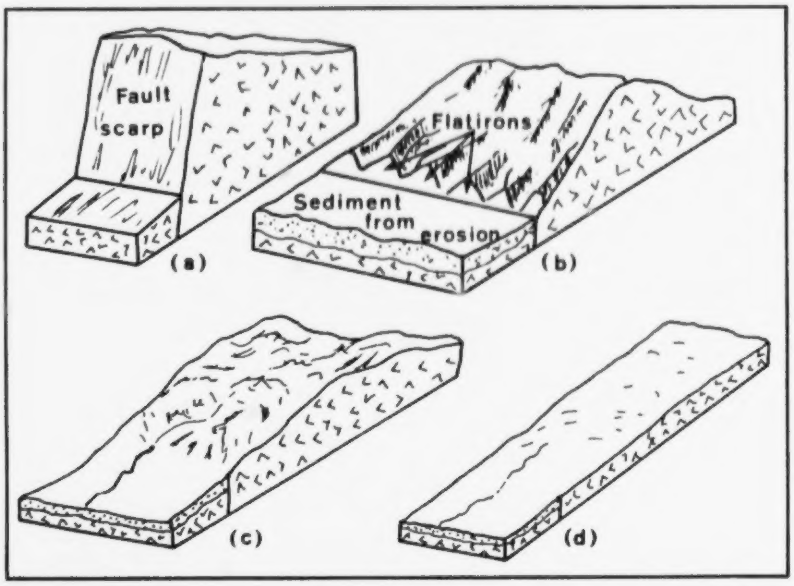


Figure 12.26. (a) is a newly faulted mountain; (b) is the same mountain after erosion has carved deep ravines and flatirons in the fault scarp; (c) is a further eroded version of the mountain with the fault line difficult to find; (d) is the remains of the old faulted mountain.

C. Dome mountains: These are dome-shaped mountains that vary in size and shape from about a kilometer in diameter and almost circular to many kilometers in diameter and elliptical. Most of the large dome-shaped structures are rather ancient in geologic age. Our closest dome is the Ozark Dome in Missouri. The Black Hills, of South Dakota, are also dome mountains as are the Adirondack Mountains in New York State.

1. Origin: Dome mountains are formed by an intrusion, usually some form of magma (for example, a batholith or laccolith), or perhaps salt, rising and pushing up the overlying crustal rocks.
2. Effects of erosion: As erosion attacks the dome with its usual vigor, the rock layers are removed from the center of the dome. If rock layers of alternating strength and weakness exist on the flanks, ridges circling the dome will probably form. Steeply dipping ridges on the flanks of the dome are called hogbacks. (They can also form in folded mountains.) (See Figure 12.27) As the hogbacks erode, they may form triangular slabs resembling the tip of an iron and (remarkably) are called flatirons. (Note: Flatirons can form on both fault-block mountains and on domes!) (See Figure 12.27) If the dip of the rocks on the flanks of the dome is slight rather than steep as in a hogback, the ridges are called cuestas. (See Figure 12.27) Hogback or cuesta ridges are separated by narrow circular valleys of weak rock. Eventually, the highly eroded dome will be stripped of the sedimentary rocks in the central portion of the dome, exposing the core of the dome which is frequently granite. The Elephant Rocks area near Ironton, Missouri, is an exposure of the core of the Ozark Dome. The presidents' faces at Mount Rushmore are carved into the granite core of the Black Hills Dome. If nothing interrupts the cycle of erosion, all will eventually be flattened. However, it is important to remember that the structure will still exist beneath the erosion surface.

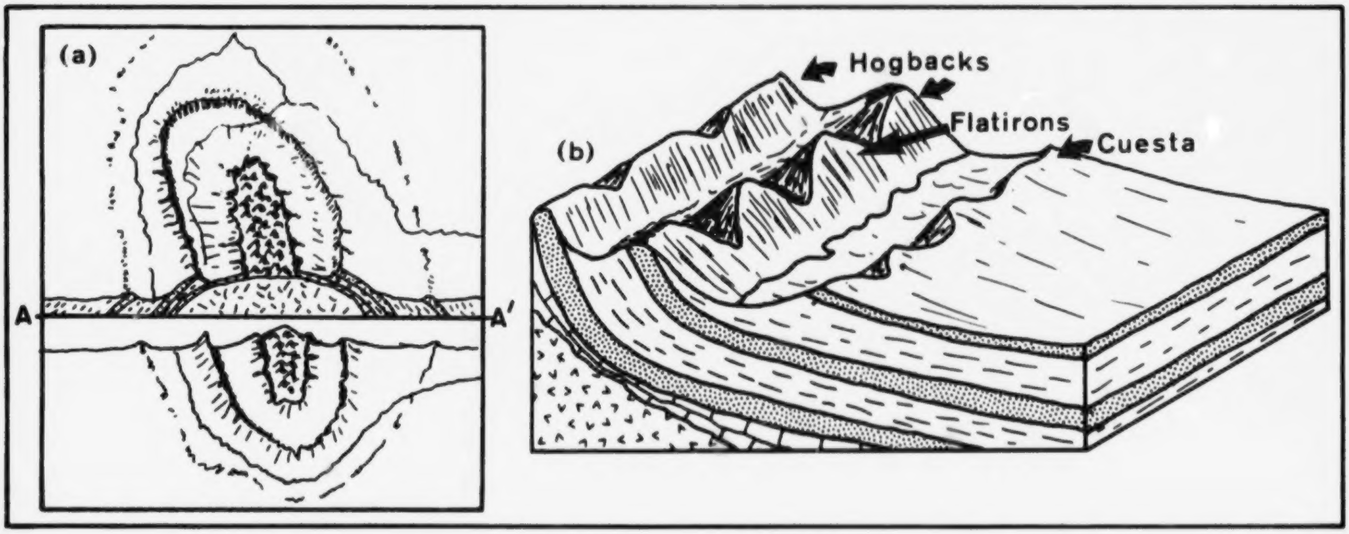


Figure 12.27. (a) illustrates a dome that has undergone enough erosion to expose the granite core. A-A' is a cut through the dome to illustrate the subsurface structure. (b) is one section of a dome enlarged to show detail.

D. Volcanic mountains: As you learned in Chapter 11, volcanic mountains are formed by the accumulation of molten rock and rock debris expelled from beneath the earth's surface. Examples include the Hawaiian Islands and the Cascade Mountains in northern California, Oregon, and Washington. For a review of the different volcanic cones, see Chapter 11.
   1. Origin: Volcanoes emerge with two different types of plate movement. The first is when plates are pulled apart (divergent plates). With the separation of the plates, magma is able to surface onto the crust to create oceanic ridges and ocean basin volcanoes. The second is when plates collide, and one plate slides down under another (subduction zone of convergent plates). The diving plate is heated up by the friction of the moving plates, and some of the crust is partially melted. The molten rock then rises to possibly create a volcano. Volcanoes may also form above plumes.
   2. Effects of erosion: Depending upon the looseness of the material composing the cone, erosion starts to work on the cone immediately and works at differing speeds. Loosely consolidated cones can be leveled quickly. Deep narrow gullies and ravines rapidly form, with water carrying away much of the cone. In cold climates, glaciers aid in the erosion. Not long for this world, the volcanic cone is quickly flattened, occasionally leaving a stump of its neck or dikes sticking above the ground for a short while as a brief reminder of its existence.

E. Complex mountains: All mountain building does not occur in separate episodes. Up until now, simply the basic mountain types were considered. When there are many types within an entire mountain range, they are called complex mountains. The Rocky Mountains are complex mountains, having all basic mountain types represented. The European Alps are extremely complex, and geologic mapping efforts have been put forth for the last hundred years with no final end product as of yet available.
   1. Origin: Complex mountains appear to have begun as geosynclines along continents. Plate movement then shoved the geosynclines up into mountain ranges. In the case of the Himalayas, the Indian subplate rammed into the Eurasian plate with such force that the final result was extreme folding and twisting, much breakage, overturned folds, and thrust faulting to distances from 48 to 64 kilometers (30 to 40 mi). All of this was accompanied by volcanic activity. In the case of United States' western mountains, it is now believed that they formed by an unfamiliar form of subduction. Rather than a crustal plate descending at a sharp angle beneath a continental plate, in this case, the crustal plate descended at a very slight angle. The virtually horizontal movement of one plate under the other was responsible for the Rocky Mountains and others found in western United States.
   2. Effects of erosion: The effects of the erosion of folded, faulted, and volcanic mountains have been discussed separately. Because complex mountains are a combination of mountain types, the effects of erosion depend upon the predominant type in a specific area.

F. Residual mountains: These are mountain-like structures that are composed of horizontal rock. Our definition of mountains stated that the rocks must be structurally disturbed. Therefore, by our definition, residual mountains do not classify, technically, as mountains. They will be discussed in Chapter 13 with plateaus.

SEE ACTIVITY 12.2

SEE ACTIVITY 12.3

390

IV. Major mountain ranges of the world: Mountains form part of every continent on the earth.
  A. North America: The Appalachians are on the East Coast, with the Sierra Nevadas, Cascades, and Coast Ranges on the West Coast. The Rocky Mountains are east of the Sierra Nevadas in the west-central states and extend from Alaska to Mexico.
  B. South America: Along the Pacific Coast, the Andes form the southern hemisphere counterpart of the Rockies.
  C. Asia: Located in south-central Asia are the Himalayas.
  D. Africa: Near the equator in central Africa are the Ruwenzori Mountains, also known as the "Mountains of the Moon." South Africa has the Dragensberg Mountains, while Northwest Africa has the Atlas Mountains.
  E. Europe: The Alps extend from France through Switzerland and from northern Italy into Germany and Austria. The Causasus are in southern USSR. France is separated from Spain by the Pyrenees, and the Urals divide Europe from Asia.
  F. Australia: Along the East Coast is the Great Dividing Range.
  G. Antarctica: There are several high ranges, one an extension of the Andes; however, they are almost buried in ice.

V. Mountains of the future: You Get to Predict!

SEE ACTIVITY 12.4

VI. Mountains and people: Mountains have had a profound effect on people.

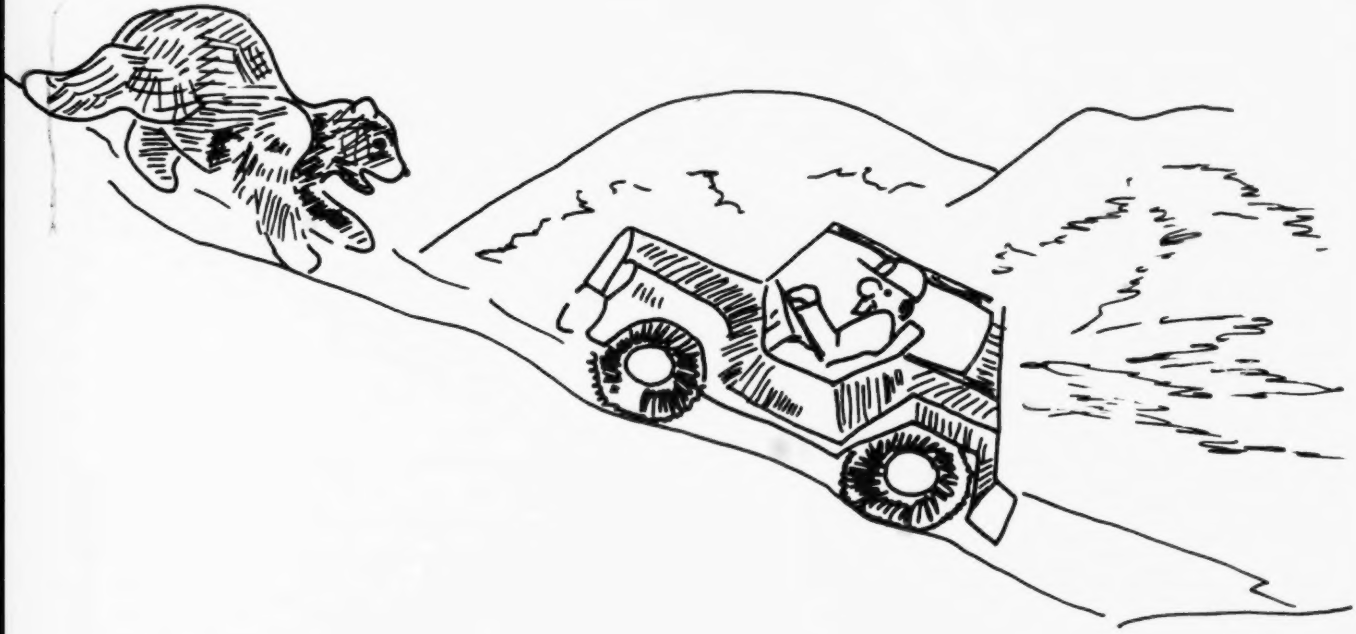
  A. Travel: The travel and migration of people have been influenced by the location of mountain ranges. In young United States, the Appalachians hindered inland travel. The rugged topography of central Africa kept the white race away for many years.

  B. Military significance: The Roman Empire was protected from northern invaders by the Alps. During World Wars I and II, Switzerland was isolated from the rest of Europe's conflicts.

  C. Economy: Forests provide wood for lumber, paper, and other products. Streams provide water power for electricity. Our greatest source of minerals is the mountains from which we get such mineral resources as gold, tin, copper, and lead.

  D. Climate: Even the circulation of the atmosphere is influenced by mountains. For instance, one reason India is so hot is that the Himalayas block the cool northern air and keep it from reaching India. Another situation occurs when moist winds from the ocean are forced up over a mountain range. The moisture in the air is cooled and drops to the mountain side in the form of rain or snow. When the air reaches the other side of the mountains, the amount of moisture it contains is considerably less. That is why there are deserts on the inland (leeward) side of coastal mountains. An example can be found where the very dry Great Basin is on the inland (leeward) side of the Sierra Nevadas in California.

  E. Recreation: The temperatures are cooler in the mountains so that summer vacation spent there gives relief from hot summer temperatures. Winters provide plenty of snow for many winter sports. The economy is also aided through recreation.



VII. Summary: As long as plates move, new mountain ranges are going to be created as quickly as the old ones are destroyed (geologically speaking). In this ongoing process, a mass of magma, for example, could pop up between two divergent plates to become a solid part of an oceanic ridge. Through time, it would be shoved away from the ridge, traveling as part of an oceanic plate. With the approach of a continental plate, (land ahoy!), the mass would go the way of the oceanic plate by diving under the continental plate in the subduction zone. The heat would become greater with depth, and the mass would become part of the liquid rock around it and rise to form a volcano along the edge of the continental plate. Erosion could carry the particles out to the geosyncline adjoining the continent, where a long vacation of rest and relaxation would result. The mass would become one of many to be compressed into rock. Continued lateral plate movement pushing and shoving the geosynclinal deposits up eventually provides transportation for the mass to leave the ocean and become part of the coastal scenic mountains. And so, on go the endless possible cycles on the "solid earth" below us, with mountains playing a prominent part.

SEE ACTIVITY 12.5

Chapter 12: Problems and Questions

1. Describe the parts of a fold.
2. Explain the difference between a symmetrical, asymmetrical, and an overturned fold.
3. Draw the strike and dip symbols to show the differences between an anticline, syncline, dome, and basin.
4. Draw the profiles of a reverse fault, normal fault, thrust fault, and strike-slip fault.
5. Describe how a geosyncline becomes a mountain range.
6. Compare and contrast the life cycles of a folded mountain range, a fault-block mountain range, a dome mountain, and a volcanic mountain.

Unit IV: Internal Processes

CHAPTER 13: Plains and Plateaus

- I. Introduction

- II. Plains
  - A. Types of Plains
    - 1. Coastal Plains
      - a) Origin
      - b) Specific Characteristics
    - 2. Interior Plains
      - a) Origin
      - b) Specific Characteristics
  - B. Effects of Erosion
  - C. Plains and Man

- III. Plateaus
  - A. Types of Plateaus
    - 1. Uplifted Horizontal Rock
      - a) Origin
      - b) Specific Characteristics
    - 2. Lava Plateau
      - a) Origin
      - b) Specific Characteristics
  - B. Effects of Erosion
    - 1. Initial Development
    - 2. Intermediate Development
    - 3. Final Development
  - C. Plateaus and Man

- IV. Summary

Related Activities

Vocabulary

Identify plain and plateau features on aerial photos.

Plot major plains and plateaus on a world map.

Problems and questions

Plain and Plateau Geo Facts

The largest high plateau is the Tibetan Plateau in Central Asia. It averages 4,896 meters (16,000 ft) above sea level and covers some 199,430 square kilometers (77,000 square miles).

The Catskill Mountains of New York are not really geologic mountains but rather a high dissected plateau.

Height above sea level (elevation) is not the only basis for determining what is a plateau or a plain. The Great Plains reach a height of some 5,200 ft. (1.6 km.), while the Ozark Plateau has a maximum elevation of only 1800 ft. (548 m.)

Chapter 13: Word List

Plateau Platitudes
Butte
Coastal Plains
Continental shelf
Great Plains
Interior Plains
Mesa
Plain
Plateau

Hum, plane or plain?
DICTIONARY

UNIT IV: INTERNAL PROCESSES

Chapter 13: Plains and Plateaus

I. Introduction: The expression "flat as a pancake" nearly wraps up any description you may have of the plains. That expression essentially defines the plains nearly as well as the official definition--a plain is any region of level or nearly level land of relatively low elevation that is underlain by horizontal layers of rock. Plateaus are similar to plains in that both are underlain by basically horizontal layers of rock. Plateaus, however, are usually higher in elevation than plains, since most plateau regions have been gently uplifted over millions of years.

II. Plains: There are four characteristics that apply to all plains despite the fact that their origins may vary. The land on a plain is generally flat. This flat land is occasionally interrupted by low hills and shallow river-cut valleys. Next, the land is underlain by horizontal sedimentary layers of bedrock. These layers of rock were formed at the bottom of either lakes or seas. At a later time, either the level of the land was uplifted or the water level was lowered to expose these beds. Last, the flatness of the land is sometimes interrupted by cuestas which may extend for long distances.

A. Types of plains: The origin of plains can differ; thus, there are two different types.

1. Coastal Plains: In the United States, the Coastal Plain includes the Atlantic and Gulf Coast region. The Atlantic Coastal Plain extends west to the Appalachian Piedmont. The Gulf Coastal Plain extends further inland with its furthest northern margin extending to the southern tip of Illinois. (See Figure 13.1) If there is a rise in sea level, the Coastal Plain is low enough in elevation to be easily flooded.

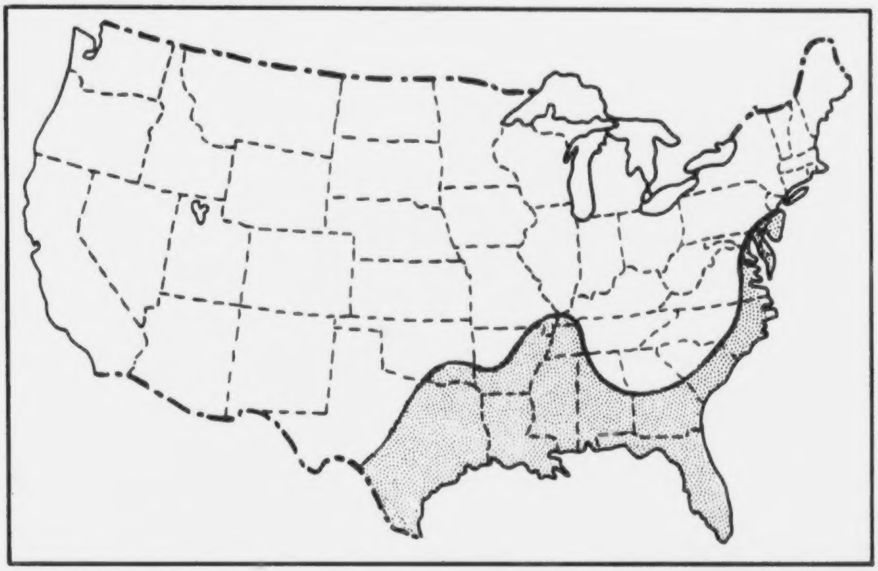


Figure 13.1. The dotted area of this map marks the approximate boundaries of the Coastal Plains.

a) Origin: The continental shelf is a relatively flat portion of a continent that is part of the ocean. (See Figure 13.2) Sediment is always being deposited along the continental shelf. This sediment can be the skeletons of marine life, it can be sediment from erosion along the shoreline, or it can be sediment from the inland areas carried to the oceans by streams. The Coastal Plain is formed when part of the continental shelf emerges from the ocean to become dry land. Again, the emergence can occur either by uplift or by the lowering of sea level. The Everglades of Florida are an example of a Coastal Plain still in the early stages of emergence.

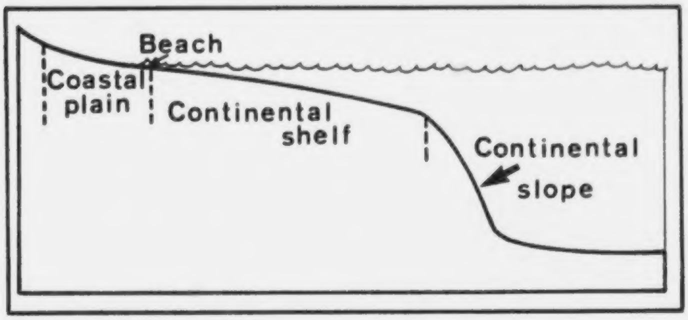


Figure 13.2. This is a profile of the edge of a continent as it slopes down and grades into the ocean floor. The continental shelf is the underwater border of a continent.

b) Specific characteristics: The rocks of a Coastal Plain dip gently toward the sea. As one moves inland, the land becomes less flat because of the increase in elevation and also because erosion has been taking place for a longer period of time. Occasionally, basins are present and are the sites of lakes or marshes. The tilted, resistant rock extends inland and can end in a cuesta. Very interesting features found on the Gulf Coast are salt domes which formed from deposits on the floors of ancient salt lakes and marginal seas.

2. Interior Plains: This type of plane includes the interior parts of the United States from the Appalachians to the Rocky Mountains. (See Figure 13.3)

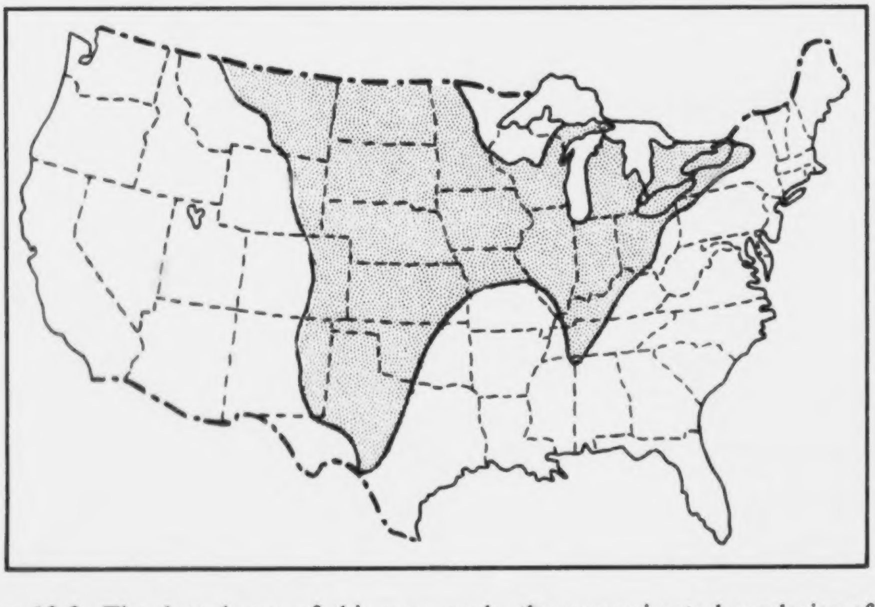


Figure 13.3. The dotted area of this map marks the approximate boundaries of the Interior Plains.

        a) Origin: The area of the Interior Plains was once the bed of a great inland sea. The deposits that were deposited by that sea now form the bedrock of the Interior Plains.
        b) Specific characteristics: Rather than being flat, the sedimentary rocks of the Interior Plains tend to gently dip in various directions due to the presence of domes or basins. Generally, the land is flat, but sometimes rolling hills break the monotony. Some of the very flattest parts of the land are the result of additional deposition by rivers and those found on abandoned lake floors. The northern portion of the Interior Plains was glaciated, and, as in the case of Illinois, for example, glaciers leveled areas that had been sites of gently rolling hills. The western portion of the Interior Plains, known as the Great Plains, has been further smoothed by stream deposits of sediments eroded from the Rocky Mountains.

B. Effects of erosion: In order for streams to cut away the land surface, the land elevation has to be higher than sea level, the higher, the better. Because streams do most of the eroding of plains, it should soon become obvious that the effects of erosion are not great. In extremely dry areas, erosion such as that found in the Badlands of South Dakota may occur. The only difference between a young and an old plain is that an old plain possesses well-developed stream valleys.

C. Plains and man: From a practical point of view, the plains are an asset to man. For example, in the United States, plains have played an important role in the development of the nation. The Atlantic Coastal Plain, with good harbors and rich soils, was home for many of the first settlers to the New World. They became the economic backbone of the colonial South. The Gulf Coastal Plain became important during the 1800's for its agricultural products such as cotton and tobacco. As Americans moved westward, the Great Plains became home for wheat farmers and ranchers. Today, as in the past, plains are regions of great economic importance to the nation. And as long as industry, commerce, and agriculture require flat land, good harbors, and rich soil, the plains will continue to be important.

III. Plateaus: As noted earlier, the original surface of a plateau is usually flat, like that of a plain. The later uplift of the flat low-lying region will allow erosion to cut much deeper valleys than can be found on plains. This deep valley development is also common on lava plateaus.

A. Types of plateaus: Because the origin of the rock composing plateaus varies, there are two different types.

1. Uplifted horizontal rock: Plateaus of this type are the greater in size of the two types. There are two plateaus of this type in the United States. One is the Appalachian Plateau, and the other is the Colorado Plateau. (See Figure 13.4)
    a) Origin: This type of plateau is the result of crustal movement gently lifting horizontal rock layers that cover a wide area.
    b) Specific characteristics: The flat top of the plateau is carved by valleys, some of which are quite deep. During uplift, the valleys are already being formed, so that by the time the uplift reaches an end, valley development is well advanced. Resistant rock forms cliffs, while plateaus of weak rock can form badland topography containing no vegetation and displaying narrow ravines and sharp crests instead of hills and valleys ordinarily seen. An example is found in the Painted Desert of Arizona. Sometimes, the rocks of the plateau may have enough dip to form cuestas. The Indians of Mesa Verde built their homes in shelter caves in and on a cuesta near the edge of the Colorado Plateau.

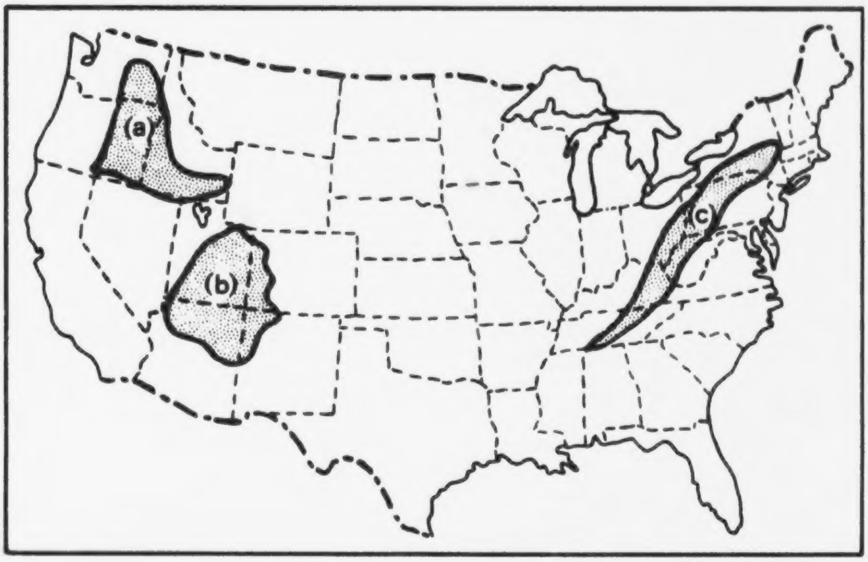


Figure 13.4. The shaded areas show the plateau locations in the United States. (a) is the Columbia Plateau, (b) is the Colorado Plateau, and (c) is the Appalachian Plateau.

2. Lava plateau: Unlike the uplifted sedimentary rock plateaus, lava plateaus are elevated areas of land that have attained their elevation through consecutive lava flows. A major lava plateau found in the United States is the Columbia Plateau, located in the Pacific Northwest. (See Figure 13.4)
    a) Origin: Because the Columbia Plateau is the only lava plateau in the United States, its origin will be discussed. Lava plateaus are composed primarily of basaltic lava which, as you no doubt recall, is highly fluid. This allows plateaus to form rapidly. The lava of the Columbia Plateau overwhelmed mountains that were nearly 1.6 kilometers (1 mi) high. Most of the lava came from fissures, and the total volume of lava covered 250,200 cubic kilometers (60,000 mi^3). It might be pointed out here that the Columbia Plateau did not form as the result of one flow but rather from several disrupted flows. Evidence of this can be seen where soil and sediment are interbedded with lava flows.
    b) Specific characteristics: Lava plateaus originate quickly (as opposed to the slower uplift forming the other type of plateau), and they resemble a plain for a long period of time because valleys could not form while the lava was flowing. Lava plateaus are generally smaller than plateaus formed by uplift.

B. Effects of erosion: Because plateaus are higher than plains in elevation, they are exposed to much more erosion. However, the end product depends upon the climate and the type of rock. There are three general stages in plateau erosion. (Lava plateau erosion was discussed in Chapter 11, so the topic now will just involve erosion of horizontal rock layers.)
1. Initial development: Young plateaus can be recognized by their deep stream valleys separated by broad, flat areas.

2. Intermediate development: The topography becomes more rugged. (See Figure 13.5) The Catskill region in New York State is in this stage of development. The Catskills are often referred to as residual mountains. However, recall that our definition of mountains specifies that they be structurally disturbed. Therefore, residual mountains are simply dissected plateaus composed of horizontal rock. In the Appalachian Plateau, of which the Catskills are a part, erosion is different from the dry western plateaus because the climate is more humid. The slopes tend to be rounded, and it is less obvious, because of the vegetarian cover, that the structures are of flat-layered rock. The eastern, humid area becomes much more dissected than the western counterpart. The result is relatively few flat, elevated areas that are undissected by stream erosion.

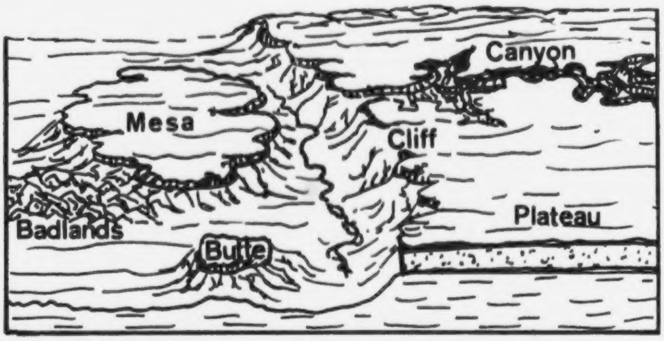


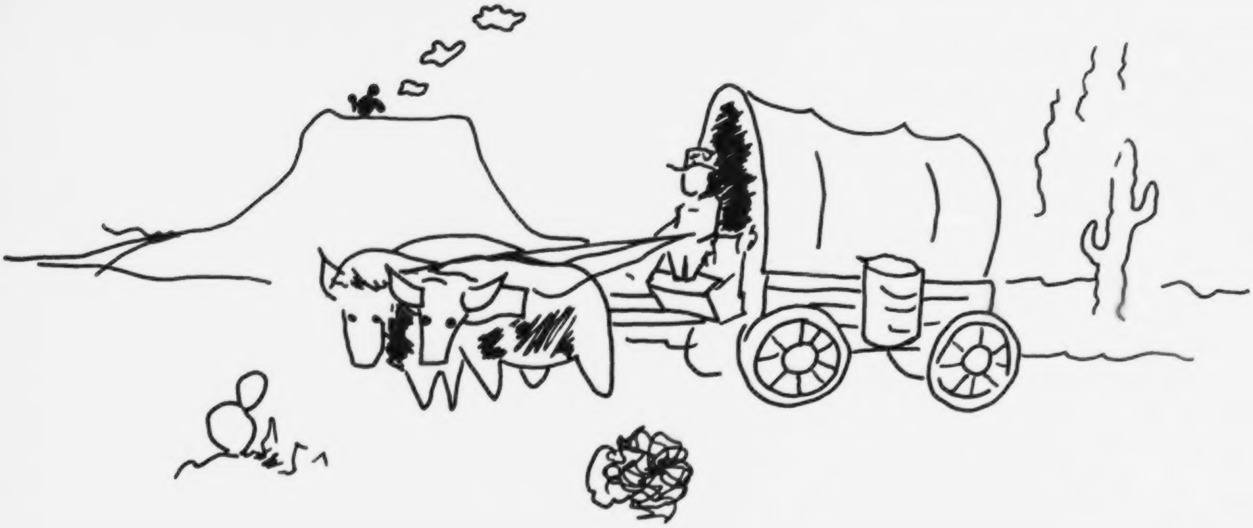
Figure 13.5. Shows various stages of plateau erosion in a dry climate.

3. Final development: By this time, the plateaus are almost entirely worn down. Traces of the plateau can be seen occasionally. In dry regions, the remains of plateaus are in the form of flat-topped, steep-sided structures. Those with broad tops are called mesas; those that are smaller with narrow tops are called buttes. (See Figure 13.5) They owe their existence to a protective cap rock such as sandstone or lava. The Kaibab Plateau in the Colorado Plateau area is a well known example of a mesa. In humid regions, the slopes and tops of the remains, again, are more rounded.

C. Plateaus and man: Plateaus can be useful to humanity, often in subtle ways. Lava plateaus weather down into fertile soil. The Colorado and Appalachian Plateaus attract tourists. The Grand Canyon has provided untold geologic knowledge to people about the earth's geologic history. In addition, plateaus have long served other useful functions for humanity. Early Indians could stand (or sit astride their ponies) and watch the wagon trains move the White Eyes westward. This practice enabled them to pick better spots for ambush. These were obviously plateaus in final development. They also enabled Indians to send smoke signals more clearly because the sky was the backdrop for the smoke rings. It scared the passengers of the wagon trains so that they would hurry faster to the ambush site.

SEE ACTIVITY 13.1

SEE ACTIVITY 13.2



IV. Summary: Plains may form either as Coastal Plains resulting from deposition on the continental shelf or as Interior Plains resulting from deposition in inland seas. They are not greatly affected by any kind of erosion other than stream erosion. They are the "Breadbasket" of our country in addition to providing convenient industrial sites. Other than being composed of horizontal rocks, plateaus differ from plains both in origin and effects of erosion. Plateaus result either from broad horizontal uplift or from accumulation of lava. Their higher elevation makes them much more susceptible to erosion and are thus the possible sites of canyons and more rugged topography. Lava plateaus provide fertile soil, but otherwise, plateaus are of less practical value to people than plains. If one prefers to be less practical, however, it might be said that plateaus come a heck of a lot closer to being some of the scenic wonders of our earth than do plains.

Chapter 13: Problems and Questions

1. Compare and contrast a Coastal Plain and an Interior Plain.

2. Compare and contrast the Columbia, Colorado, and Appalachian Plateaus.

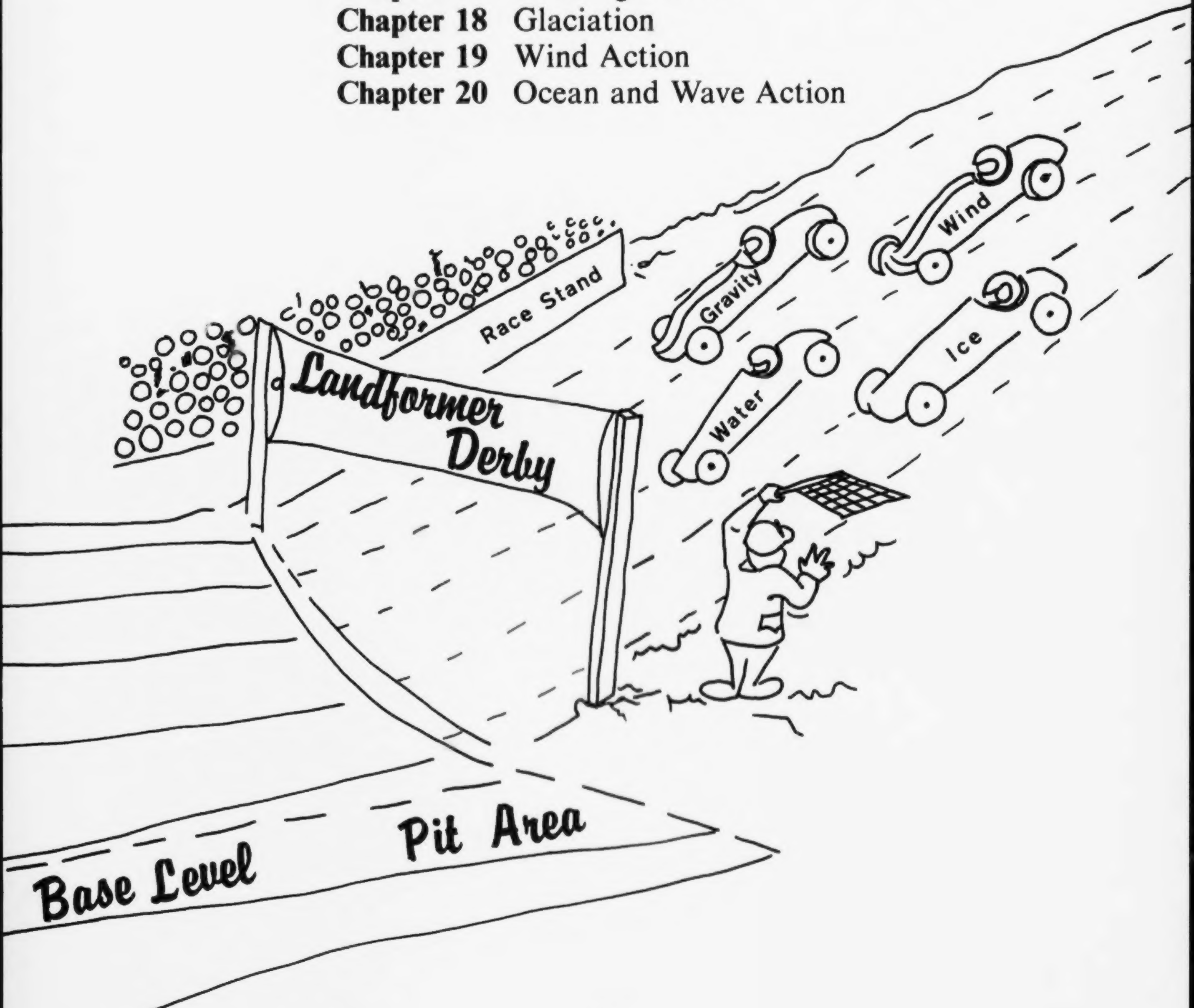
3. Describe the three (3) general stages of plateau development.

UNIT CONTENTS

UNIT V

External Processes

Chapter 14 Weathering
Chapter 15 Mass-wasting
Chapter 16 Groundwater
Chapter 17 Running Water
Chapter 18 Glaciation
Chapter 19 Wind Action
Chapter 20 Ocean and Wave Action



Race Stand
Landformer Derby
Gravity
Wind
Water
Ice
Pit Area
Base Level

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Unit V: External Processes

CHAPTER 14: Weathering

- I. Introduction
- II. Weather and Climate
  - A. Differences in Weather and Climate
  - B. Controls of Climate
    - 1. Latitude
    - 2. Altitude
    - 3. Prevailing Winds
    - 4. Topography
    - 5. Relationship to Bodies of Water
    - 6. Ocean Currents
- III. Types of Weathering
  - A. Physical (mechanical) Weathering
    - 1. Frost Action
    - 2. Changes in Temperature
    - 3. Exfoliation
    - 4. Plant Action
    - 5. Animal Action
  - B. Chemical Weathering
    - 1. Oxidation
    - 2. Hydrolysis
    - 3. Carbonation
- IV. Factors that Influence Weathering
  - A. Climate
  - B. Rock Composition
  - C. Rock Structure
  - D. Slope
  - E. Time
- V. Products of Weathering
  - A. Soil
    - 1. Factors that Influence Soil Development
      - a) Parent Material
      - b) Climate
      - c) Organic Life
      - d) Slope
      - e) Time
    - 2. Soil Profile
      - a) A-Horizon
      - b) B-Horizon
      - c) C-Horizon
    - 3. Soils and Humanity
  - B. Additional Products of Weathering
    - 1. Petroleum
    - 2. Mineral Products

Breakin' up is hard to do

VI. Problems Caused by Weathering

VII. Summary

Related Activities

Vocabulary

Demonstrate chemical weathering and its results.

Work a puzzle using weathering terms.

Problems and questions

Weathering Geo Facts

Frost action can produce more weathering in 70 New York winters than all processes of weathering in 50 times 70 years in Egypt.

Every time a rock mass is exposed at the earth's surface, an equilibrium is established with the surface environment through chemical and physical weathering. In other words, weathering is the inevitable adjustment of rocks formed at depth to the new environment at the earth's surface.

The nature of London's air (moist air, gases from factory smoke, and exhaust from internal-combustion machines) is such that it was causing rapid weathering of the limestone of Westminster Abbey. Extensive reconstruction was necessary.

Old sandstone gravemarkers in New England have entirely lost their inscriptions by weathering. After three centuries, slate markers are readable. Granite and marble show only a slight amount of abrasion after a century.

Joseph Black, of Edinburgh, discovered carbon dioxide. In less than 80 years after his death, the inscription on marble in his memory was illegible. Ironically, it was because of the action of the gas that he discovered.

Frost action can exert enough pressure to split containers with 2.54 centimeters (1 in) thick steel walls with explosive force.

Most high mountain peaks have been so weathered by frost action that solid, unbroken rock is hard to find.

The rate of soil formation varies under different conditions from several meters per century to less than 2.54 centimeters (1 in) in 10,000 years.

Chapter 14: Word List

Weathered Words

A-Horizon
B-Horizon
Carbonation
Chemical Weathering
C-Horizon
Eluviation
Erosion
Exfoliation
External processes
Frost action
Horizon
Humus
Hydrolysis
Illuviation
Leaching
Oxidation
Parent Material
Physical Weathering
Regolith
Soil
Soil Profile
Solution
Topsoil
Weathering

Straight Terms

Carcass
Conspicuous
Residue
Transitional

UNIT V: EXTERNAL PROCESSES

Chapter 14: Weathering

I. Introduction: In the previous unit, Unit IV, internal processes were studied. As you recall, internal processes are those that take place inside the earth. Unit V is going to deal with external processes, those activities that take place on or near the surface of the earth. Although the subjects of Units IV and V are examined separately, it is important to remember that internal and external processes are always interacting with each other. For instance, a mountain cannot be eroded away (external process) if it was not first created (internal process). Three processes work externally to wear down the land: weathering--the breaking up of rock; mass-wasting--the downward pull of rock fragments by gravity; and erosion--the removal of rock material. The agents of erosion include groundwater, running water, glaciation, wind action, and wave action. This chapter is going to deal with weathering. Weathering, in more detail, is the breakdown of rocks or minerals at or near the surface as a result of the interaction of the atmosphere, water, and plant and animal life. It must be understood that erosion is different from weathering; erosion is the removal of earth or rock material. There are instances when they may seem the same, but further examination will prove they are not.

II. Weather and Climate: Before discussing the process of weathering upon the physical earth, an overview of the atmospheric processes that actually cause weathering is important.
   A. Differences in weather and climate: Weather is the sum of all atmospheric properties such as temperature, precipitation, pressure, and winds at a specific point in time. Climate is, in its simplest form, the average weather for a given region over many years.
   B. Controls of Climate: A combination of factors determine a region's climate. These factors include the following:
      1. Latitude
      2. Altitude
      3. Prevailing winds
      4. Topography
      5. Relationship to bodies of water
      6. Ocean currents

III. Types of weathering: Weathering can be accomplished in two ways.
   A. Physical (mechanical) weathering: Physical weathering results in the breaking up of rock into smaller fragments and constitutes the initial breakdown of bedrock. It thereby exposes new surfaces to chemical weathering. It occurs, for the most part, in areas of high latitude and elevation. Once weathering has occurred, the agents of erosion carry away the weathered particles. The following are agents of physical weathering.
      1. Frost action: Frost action is the process in which water enters cracks or fractures in rock, freezes, and causes the rock to break apart. (See Figure 14.1) Nearly every rock contains cracks of all sizes. Water enters these cracks, expands by 9 percent of its original volume while freezing, and forces the rock to break into angular fragments. The ease with which the whole process occurs explains why frost action is the main agent of physical

weathering. Frost action creates major highway problems in areas where temperatures fall below freezing at some time during the year and moisture is present. In cold weather, water seeps down into cracks in concrete and blacktop. When the water freezes, it expands and widens and deepens the crack. Over a period of time the great American "pothole" forms. While appearing a minor problem, on a national basis, millions of dollars are spent patching the highways.

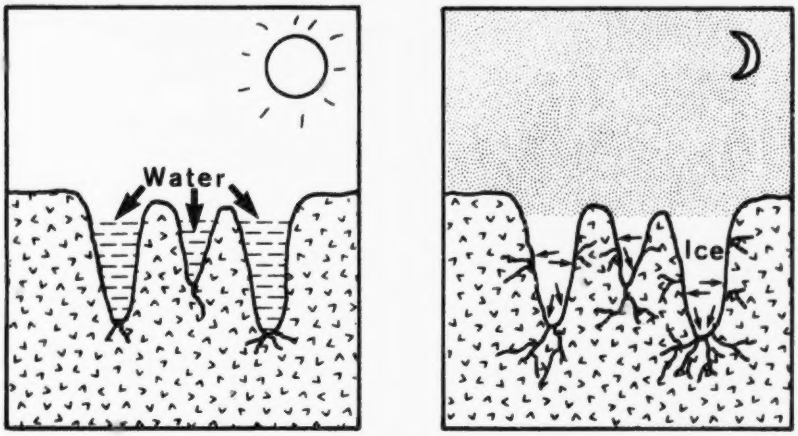


Figure 14.1. An illustration of frost action. The arrows in the nighttime figure at the right indicate pressure exerted by the ice.

2. Changes in temperature: When rocks become hot, they expand, becoming larger; when they cool, they contract, thereby shrinking. In areas where the temperature difference between day and night is great, it is not certain that temperature changes will break up fresh hard rock, although this agent does assist in breaking up partially weathered rock. Often, it is only the outer layers that are affected, so that a layer of rocks separates from the rest of the rock and eventually peels off, much like layers of an onion peel off.
3. Exfoliation: A physical weathering process in which curved layers of rock are broken away from the rock mass. This usually occurs when internal pressures force the outer layers of rock outward. The resultant rock structures are known as exfoliation domes. This process is most common in igneous rocks such as granite and diorite. Famous examples of exfoliation domes are Stone Mountain, Georgia and Half Dome in Yosemite National Park in California. (See Figure 14.2)

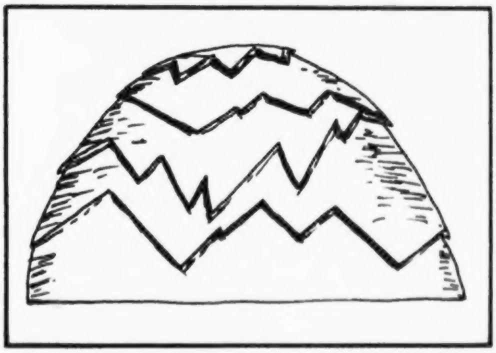


Figure 14.2. An illustration of exfoliation. (The illustration is of a rock and not an egg.)

4. Plant action: Plants are of importance in the breakup of rock already affected by other physical and chemical processes. The roots of plants wedge in joints of rocks. As they grow, they enlarge the space between the rocks by exerting enough pressure to dislodge fragments. (See Figure 14.3) As a comparison, think about how grass and tree roots break up sidewalks and building foundations.

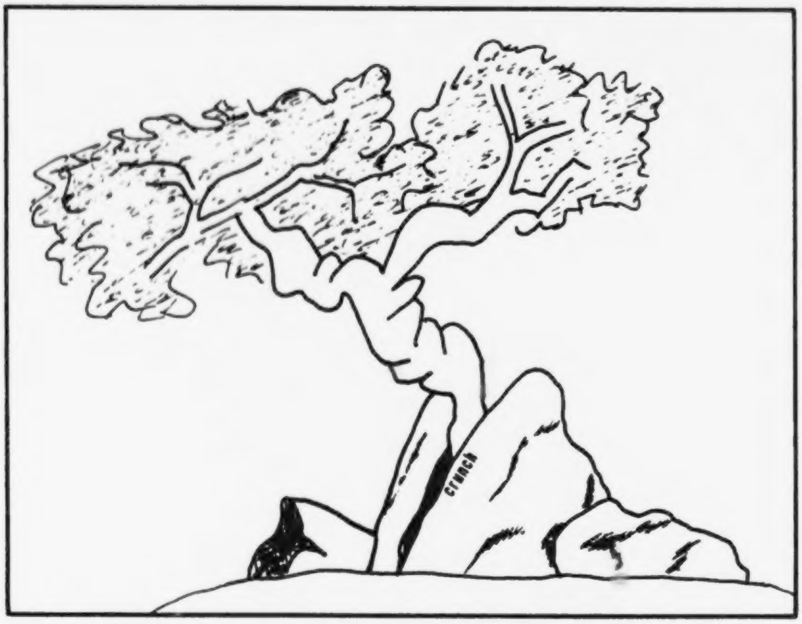


Figure 14.3. An illustration of plant involvement in weathering. Here the tree is splitting the rock apart.

5. Animal action: Burrowing animals have an effect similar to that of plants. When the animals dig into a crack, rock particles are brought to the surface. The surfacing of the rock particles allows them to be weathered. Earthworms eat soil to obtain organic material. In so doing, they grind and dissolve particles and thus help the weathering process. And last, but not least, there is HUMANITY, armed with its dynamite and bulldozers.

B. Chemical weathering: Chemical weathering results in a change in the composition of the original material so that the end product is something new. In physical weathering, the same rocks are present before and after weathering; their size is simply different. In chemical weathering, different elements or compounds are present after the weathering has taken place. Water plays a very important role in chemical weathering; therefore, it stands to reason that chemical weathering is more predominant in warm, humid climates. As water comes in contact with rocks, the elements or compounds in the rocks combine with the hydrogen or the oxygen (the elements comprising water) to produce new elements or compounds. There are three types of chemical weathering.

1. Oxidation: Oxidation is the process whereby oxygen reacts with elements or compounds, especially iron, aluminum, or silicon, to produce new minerals. Oxidation is most obvious and is strongly activated in warm climates. Rust is the result of the oxidation of iron. (See Figure 14.4) Bauxite (which is mined and then used to make airplanes, for example) is the result of the oxidation of aluminum.

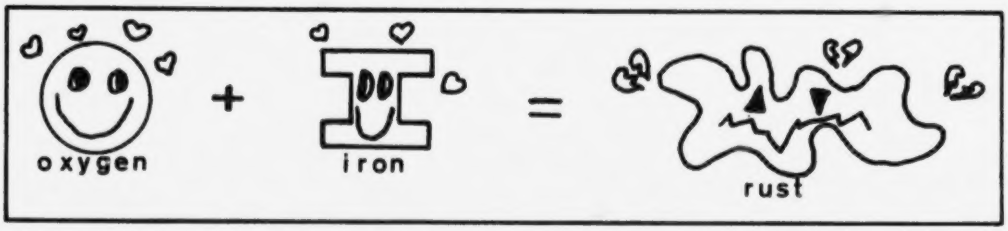

oxygen
+
iron
=
rust

Figure 14.4. An illustration of the oxidation of iron to produce our friend rust.

2. Hydrolysis: In this process, water molecules react with various minerals to produce something new. A good example is when feldspar and water react together to make sand and clay. (See Figure 14.5) This process also occurs most rapidly in a warm climate.

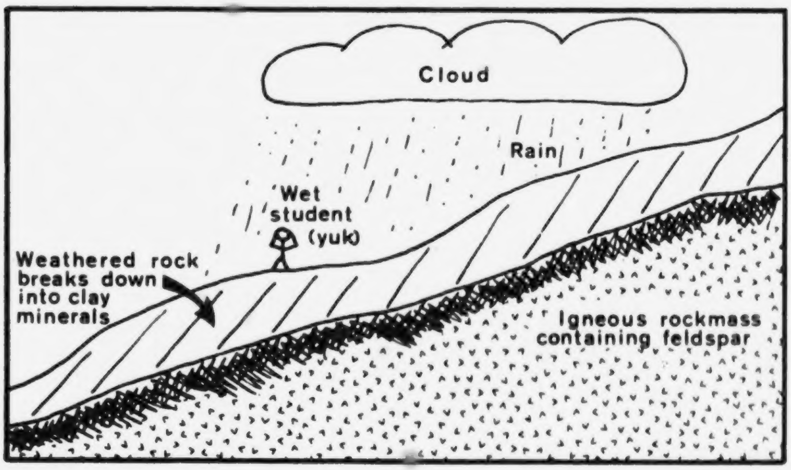

Cloud
Rain
Wet student (yuk)
Weathered rock breaks down into clay minerals
Igneous rockmass containing feldspar

Figure 14.5. An illustration of hydrolysis. The igneous rock mass containing a high feldspar content is chemically weathered by a reaction of water and the feldspar. The end result is clay mineral deposit.

3. Carbonation: Carbonation is the combining of carbon dioxide with rain water to form a weak acid (carbonic acid). It then dissolves carbonate rocks such as limestone, dolomite, and marble. (See Figure 14.6) When carbonation occurs on the exposed surface, elaborate pits, grooves, and cup-shaped hollows result. Deep below the surface, caves can result from carbonation.

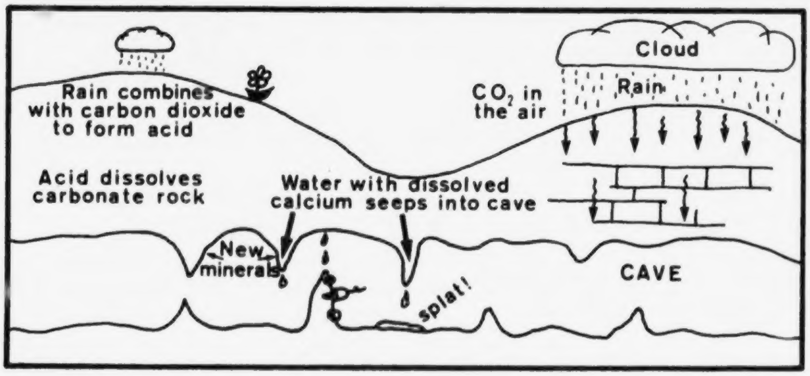

Cloud
Rain combines with carbon dioxide to form acid
CO_2 in the air
Rain
Acid dissolves carbonate rock
Water with dissolved calcium seeps into cave
New minerals
CAVE
splat!

Figure 14.6. An illustration of the carbonation process. Rain combines with carbon dioxide in the soil to form a mild acid (carbonic acid). The carbonic acid, in turn, dissolves the soluble rock.

IV. Factors that influence weathering: There are several factors that influence how rapidly a rock will weather. Please note most of these factors act in combination with one another, not independently.

A. Climate: Temperature and precipitation have a great effect on weathering. Climate affects the speed of the process, and it helps determine whether physical or chemical weathering is dominant in a specific region. In moist, warm climates, such as tropical rain forests, chemical weathering predominates. However, physical weathering is dominant in dry, cold climates such as northern latitudes or at higher elevations. It also determines the amount and type of plant and animal life.

B. Rock composition: As you know (hopefully), certain minerals are more resistant than others. In addition, the way the mineral grains are held together is important in how a rock will weather. Granite, being composed of resistant minerals like quartz and feldspar and formed in interlocking crystals, is much more resistant to the forces of weathering than is shale, a poorly compacted mass of clay and silt.

C. Rock structure: In this instance, rock structure refers to the pattern of cracks (joints) and bedding planes. The more broken the rock surface is, the easier the rock will weather either chemically or physically. Simply put, the more exposed surfaces the rock has, the easier it is to wear out.

D. Slope: On steep slopes, weathered material is continually being washed away by erosion, exposing fresh material to be weathered. However, on gentle slopes, the weathered material can accumulate, protecting the underlying rock from the immediate onslaught of weathering. In addition, vegetation can more easily grow on a gentle slope, thus having a stabilizing effect.

E. Time: Almost anything will weather if given enough time. For instance, tombstones are nearly always made of granite, because the resistance of granite will allow it to remain at its post eternally (speaking in terms of, at the most, a few hundred years). In geologic time, the granite will eventually break down as all rocks are destined to do.

V. Products of weathering: Most of us do not think of weathering as an impressive process, at least in terms of affecting people. Wrong, again!

A. Soil: Yes, soil: The material almost all our food comes from is a product of weathering. Soil has many definitions depending upon how technical or to whom you speak (geologists, soil scientists, farmers, etc.). For our purpose, soil is a combination of weathered rock, organic matter and moisture that is capable of supporting plant life. Soil is not dirt! Dirt might be soil, but not the other way around. Figure that one out.

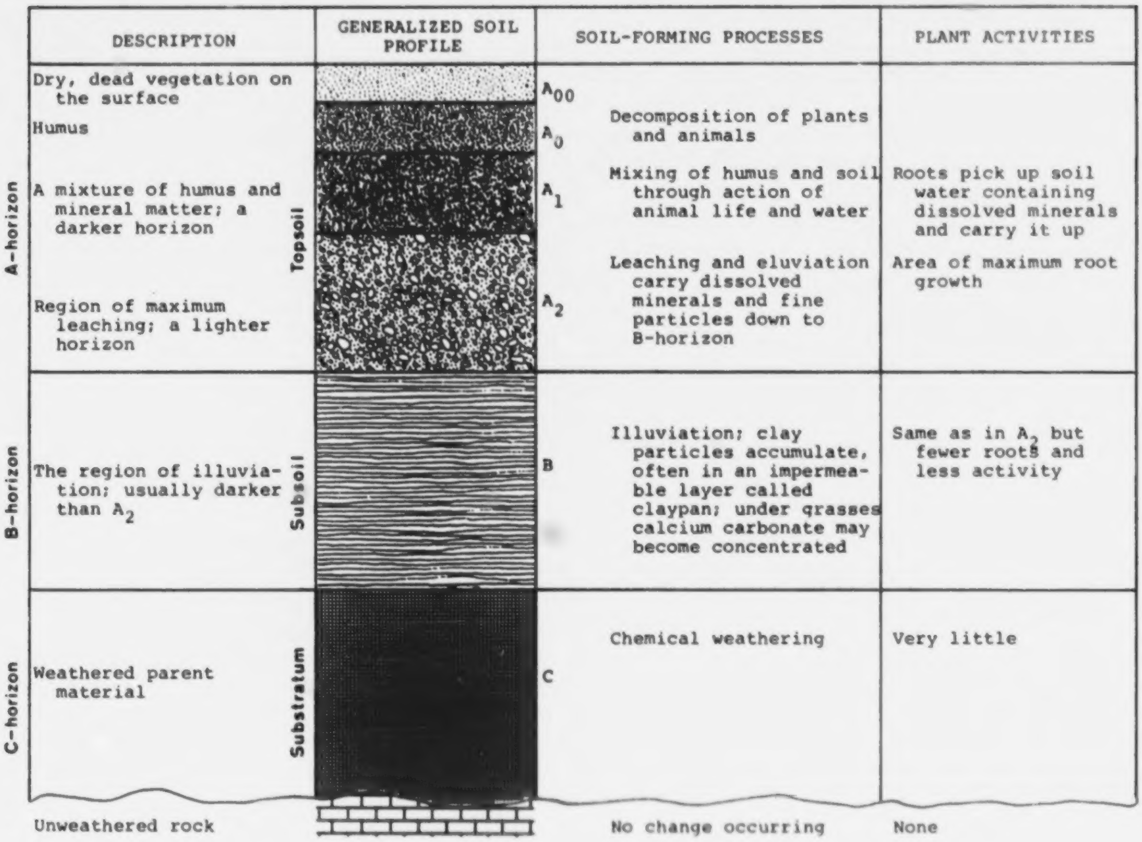
1. Factors that influence soil formation: Soils are formed through the interaction of five factors--parent material, climate, organic life, slope, and time. The first three factors (parent material, climate, and organic life) are the agents in the process and provide the elements of soil. The slope and time are the controls of the soil formation process. Each will be discussed separately.

a) Parent material: Parent material is the original material from which soil is derived. Soil begins as finely divided rock fragments produced by the weathering and erosion of such parent materials as granite, schist, shale, sandstone, lava, sand, clay, silt, or gravel. In such glaciated areas as Illinois, the parent materials include glacial materials. The parent material influences the type of soil which is being formed. The minerals of the parent material determine the mineral composition of the soil. In turn, the mineral composition affects the suitability of the soil for plant life.

b) Climate: The temperature and precipitation of an area will determine the type of weathering that will occur. They also influence the type of vegetation that will grow in the soil. The amount of water seeping through the soil has a tremendous influence on the presence (or absence) of various minerals. Leaching is the process of removing soluble minerals. Heavy rains tend to leach the soil, and if an essential mineral is taken away, plant growth may be less than healthy.

   c) Organic Life: While soils are forming and after they have formed, living organisms move in. As they die, they add dead organic matter to the top layers of the soil. The dead organic matter then decomposes to become humus (the name given to partly decomposed organic matter such as dead leaves, roots, fruits, stems, and carcasses of insects, worms, animals, and bacteria). Not only do plants add humus to the soil, but also their roots aid in breaking up the soil. In addition, roots draw desirable minerals up from the lower levels and into plants. When plants decay, minerals remain in the soil where they are needed.
   d) Slope: The slope of the surface helps to control the amount of moisture found in the soil and the growth of plants. It also affects the amount of surface erosion. Obviously, a steep slope is going to have more soil taken from it than a gentle slope. Surface erosion is a natural process as long as it does not proceed too rapidly.
   e) Time: The time needed for the development of all the soil particles depends upon the other factors of soil formation. Under the most perfect conditions, it takes 200 years and, under less than perfect conditions, up to several thousand years to develop.

2. Soil profile: When you see a fresh hole in the ground that has not been disturbed, you may see a succession of different layers that are somewhat different from each other. These layers, or strata, are called horizons. A succession of horizons is called a soil profile. A method of naming each horizon according to its characteristics has been devised. It is as simple as A-B-C. (See Table 14.1 for supplemental material.)
   a) A-horizon: This comprises the uppermost layers of the soil. It is the zone of maximum leaching (the removal of soluble minerals) and eluviation (the removal by water of dissolved minerals AND clay-sized particles to lower layers). Note that the difference between leaching and eluviation is that with eluviation, clay-sized particles are carried; leaching only removes dissolved matter.) Also known as topsoil, the A-horizon accumulates organic matter from the remains of plants and animals. Thus, even though leaching and eluviation remove material, more organic matter and plant nutrients are being added. If this layer is gray, only leaching has taken place. If it is black, humus has been able to accumulate.
   b) B-horizon: This is the layer that receives the clay particles and dissolved minerals that washed down from the A-horizon. It is also called the zone of illuviation (the deposition of mineral and organic matter that has been removed from other areas by eluviation). Because of illuviation, the B-horizon is often richer in minerals than the A-horizon.
   c) C-horizon: This layer comprises the parent material of the A- and B-horizons. Through the processes of physical and chemical weathering, the C-horizon has changed from the rocks that lie below it. It is considered to be in a transitional stage, eventually to become part of true soil in the B-horizon. As a side note, it must be added that there is not always a clear difference between true soil (A and B) and parent material (C). The C-horizon is sometimes also known as regolith. Regolith is broken (weathered) bedrock, the size of which can range from clay to boulders.



	DESCRIPTION	GENERALIZED SOIL PROFILE		SOIL-FORMING PROCESSES	PLANT ACTIVITIES
A-horizon	Dry, dead vegetation on the surface	Topsoil	A_{00}	Decomposition of plants and animals	
	Humus		A_0		
	A mixture of humus and mineral matter; a darker horizon		A_1	Mixing of humus and soil through action of animal life and water	Roots pick up soil water containing dissolved minerals and carry it up
	Region of maximum leaching; a lighter horizon		A_2	Leaching and eluviation carry dissolved minerals and fine particles down to B-horizon	Area of maximum root growth
B-horizon	The region of illuviation; usually darker than A_2	Subsoil	B	Illuviation; clay particles accumulate, often in an impermeable layer called claypan; under grasses calcium carbonate may become concentrated	Same as in A_2 but fewer roots and less activity
C-horizon	Weathered parent material	Substratum	C	Chemical weathering	Very little
	Unweathered rock			No change occurring	None

Figure 14.7. Soil profile and characteristics.

3. Soils and humanity: Living in the United States, the richest agricultural country in the world, it is easy to disregard the importance of soils by taking them for granted. Yes, food comes from the soil. Soil also produces some of the raw materials for clothing. A nation's economy is strongly influenced by food production. History books remind us that the Dust Bowl wreaked havoc with the farm economy. Wars have been fought over fertile soil. Most recent was the Viet Nam war; the Communists essentially wanted the fertile and productive Mei Cong Delta. Throughout history, preceding the fall of a nation, agricultural productivity usually failed. Keep on growing that food, United States!

B. Additional products of weathering: Other than soil, there are several additional, important products of weathering.
   1. Petroleum: Petroleum has a complex and not well understood origin, but many geologists believe a chemical weathering process of organic material is a major part of its creation.
   2. Mineral products: Several minerals owe their origin to weathering. These include limonite (iron ore), bauxite (aluminum ore), (nickel ore), and various clays that form from feldspar.

VI. Problems caused by weathering: As with many processes, weathering can create some bad with the good. Frost action destroys roads and foundations through bulging. Because of escalating costs for repairs, this destruction becomes significant. Plant roots sometimes destroy sidewalks. Chemical weathering may cause cavities to form underground. This, in turn, may lead to a collapse or slumping of the surface.

VII. Summary: Earth is a thriving planet, continuing to be revitalized through the processes of weathering. Physical weathering can crumble bedrock, weakening its defenses against chemical weathering. Chemical weathering further breaks it down, yielding possibly its most important product, soil. Soil is the mainstay of humanity, enabling us to reap the harvests of other products of weathering, such as petroleum, iron, and nickel. Through caution and prudence, the human race can assure a continuity of these natural processes.

SEE ACTIVITY 14.2

Chapter 14: Problems and Questions

1. Explain the difference between external and internal processes.

2. Compare and contrast the two (2) general types of rock weathering.

3. How do weathering and erosion differ?

4. Discuss the major kinds of physical weathering.

5. Describe how temperature affects physical weathering.

6. With examples, list the four (4) kinds of chemical weathering, and explain what occurs during each.

7. Discuss the factors that determine the speed of weathering.

8. Describe the factors that influence soil formation.

9. Briefly describe each of the horizons in a soil profile.

10. Discuss why knowledge of soils is important to everyone.

11. Name some important products of weathering.

12. Describe some effects weathering has on humanity and its environment.

Unit V: External Processes

CHAPTER 15: Mass-wasting

- I. Introduction

- II. Types of Mass-wasting
  - A. Slow Flowing Types
    - 1. Soil or Surface Creep
    - 2. Solifluction
  - B. Rapid Flowing Types
    - 1. Earthflow
    - 2. Mudflow
  - C. Landslides
    - 1. Slump
    - 2. Debris Slide
    - 3. Rockslide
    - 4. Rockfall

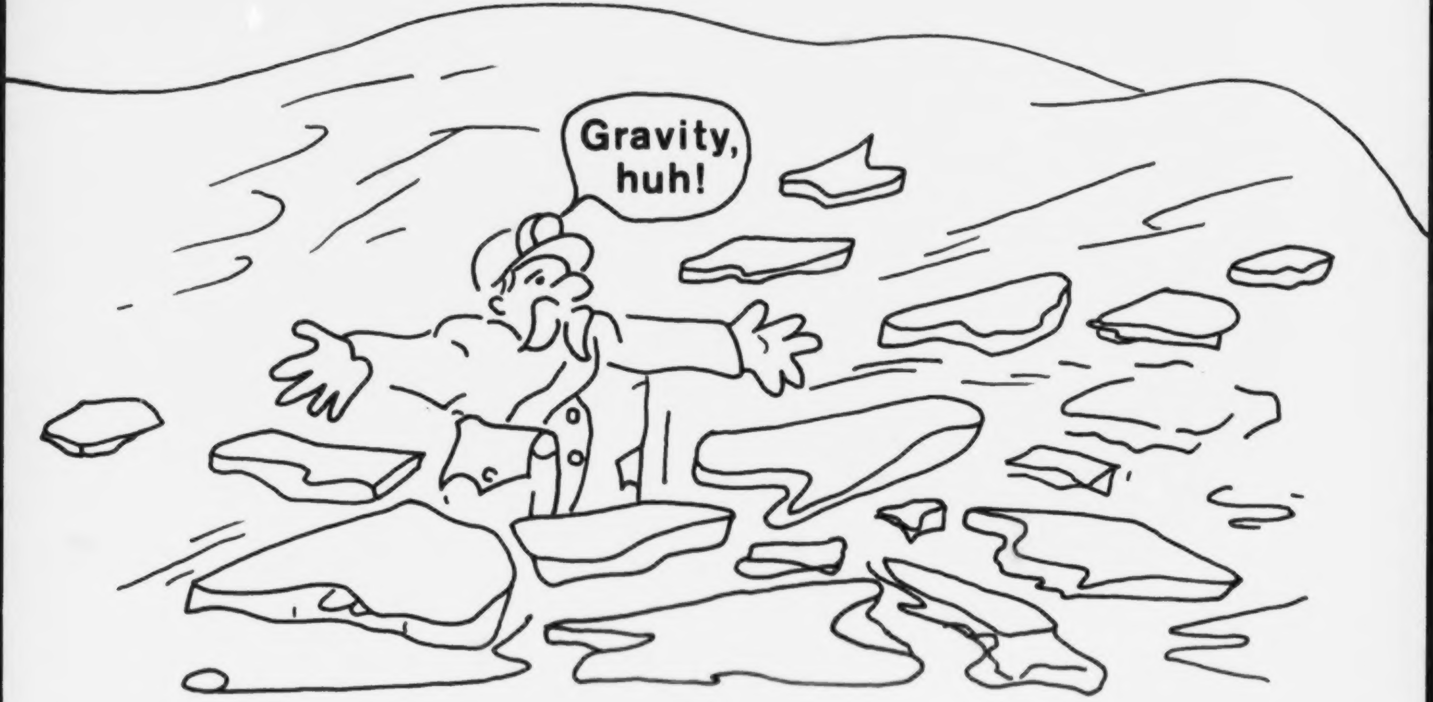
- III. Sediment Deposited by Mass-wasting
  - A. Colluvium
  - B. Talus

- IV. Factors that Influence Mass-wasting
  - A. Slope
  - B. Precipitation
  - C. Earth material
  - D. Plants
  - E. Animals
  - F. Streams
  - G. Earthquakes

- V. Hazards

- VI. Prediction

- VII. Summary


Gravity, huh!

Related Activities

Vocabulary

Identify problems of mass-wasting on aerial photos.

Identify building problems related to mass-wasting, and find solutions to these problems.

Problems and questions

Mass-wasting Geo Facts

One of the worst landslides in history was that at the Vaiont Reservoir in Italy. On October 9, 1963, more than 240 cubic meters (8,500 ft^3) of earth and rock slid into a reservoir. Water flooded over the dam, killing 2,117 people in the valley below. The dam withstood the slide, however.

In California, one of the worst mass-wasting sites has been the Palos Verdes Hills in southeastern Los Angeles County. In this area, the Portuguese Bend landslide caused approximately 10 million dollars in damages.

Weathering, mass-wasting, and erosion are the sovereign creators of relief on nearly all terrains nearly always.

At Lituya Bay in southern Alaska, in 1958, an earthquake triggered a rockfall that was estimated to weigh 90 million tons. The rock fell 915 meters (3,000 ft) into the bay. The disturbance of the bay had the same impact as 2,000 battleships being dropped from a height of four-fifths of a kilometer (1/2 mi). The resulting wave swept a dense evergreen forest clean in some portions, leaving bare rock in place of the forest.

The most destructive rockfall was on January 10, 1962. The summit of Nevada de Huascaran in Peru was the site of a fall of rock and ice estimated to have a total volume of 4,615,384 cubic meters (6,000,000 yds^3). As it went down the slope and picked up additional material, it doubled in size. From beginning to end, it lasted 15 minutes, overwhelmed seven villages, killed 3,500 people, and traveled 17.6 kilometers (11 mi).

Chapter 15: Word List

Wasted Words

Colluvium
Creep
Debris slide
Earthflow
Landslide
Mass-wasting
Mudflow
Regolith
Rockfall
Rockslide
Slide rock
Slump
Solifluction
Talus
Talus cone
Undercut

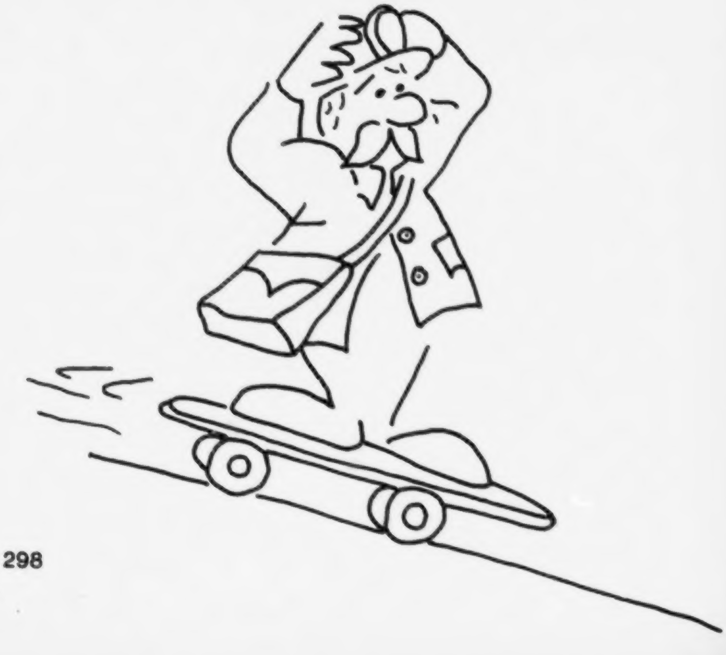
Straight Terms

Agitate
Critique
Emerge
Gravity
Lubricant
Saturated
Sparse
Torrential
Tundra
Unconsolidated
Vulnerable

UNIT V: EXTERNAL PROCESSES

Chapter 15: Mass-wasting

I. Introduction: Although gravity is always tugging downward on regolith and bedrock, they are usually strong enough to stay in place. However, when a slope enters into a situation, it is a whole new ball game, so to speak. The bedrock and regolith lose their strength, and mass-wasting occurs. Mass-wasting is the movement of rock debris down slopes under the influence of gravity and with very little help from erosional factors such as water, glaciers, or wind (although water can occasionally be a significant factor). The movements can range in size from huge slides in a rugged mountain range to small flows seen along highways and streams in early spring.



II. Types of mass-wasting: Depending upon the various influences upon the materials involved, different types of mass-wasting can occur (and with different speeds).

   A. Slow flowing types: The movement of these types is noticeable only after a long period of time.

      1. Soil or surface creep: Creep is the very slow movement of soil or rock down a slope. Weathering and the force of gravity agitate the soil. Under normal circumstances, water serves as a lubricant and provides weight for the creep to occur. It is possible to identify creep by noticing the consistent leaning of poles, trees, fences, and tombstones. (See Figure 15.1)

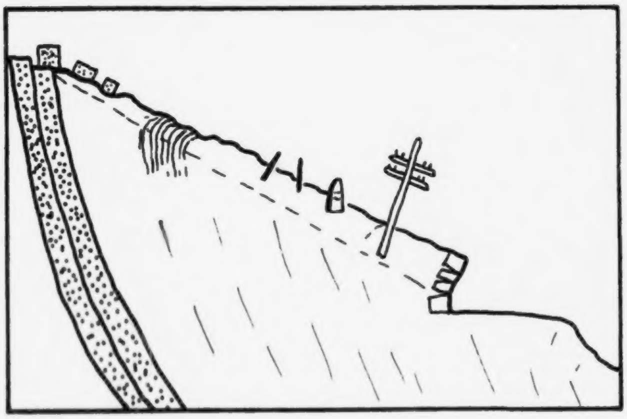


Figure 15.1. Common indications of creep.

      2. Solifluction: Solifluction is the very slow, down-slope flow of rock debris that is saturated with water. It occurs especially in cold climates where the ground surface is frozen in the winter and only partially thawed in the summer. During the summer, water saturates the thawed debris on top, and it starts to flow. It is an important process in landscape development in the region of tundra climates, frequently forming terraces as the material slips downhill. (See Figure 15.2)

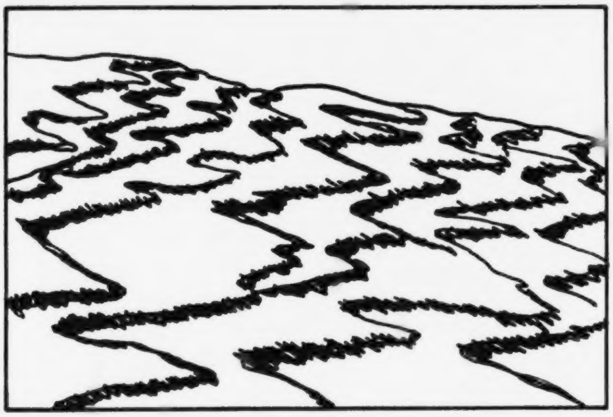


Figure 15.2. Solifluction produces a landscape with a terraced effect.

   B. Rapid flowing types: Rapid flowing types of mass-wasting tend to move as either high or low viscous fluids.

      1. Earthflow: Earthflow is the movement of water-saturated clays or silts down a slope. The movement may flow at speeds up to several meters per hour and is noticeable within hours or days of occurrence. Earthflows are common in hilly or mountainous regions of humid climates. The remaining scar is a depression on the top side of the slope surrounded by a curved scarp. The lower end bulges into a tongue-like area. (See Figure 15.3)

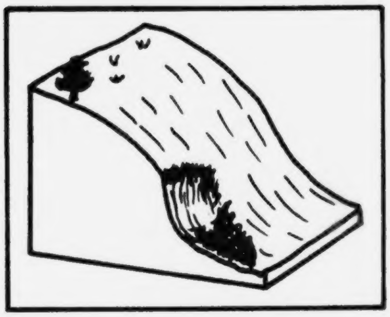


Figure 15.3. An earthflow leaves a depression on the top side of the flow and a tongue at the lower end.

2. Mudflow: This is the movement of water-saturated debris composed of fine particles down a definite channel. (See Figure 15.4) At its head, the scar is clean-cut. The floor is rough, and the steep walls are a few meters high. The consistency of this rather lovely muck is the same as that of wet ready-mix concrete. The speed of flow depends upon the amount of water present, but it can reach one kilometer an hour or faster. Mudflows can occur in deserts where conditions are of little vegetation and unconsolidated rock debris. Under these conditions, the sudden onslaught of a torrential rain can create a mudflow. There are problems associated with mudflows in the San Gabriel Range in California, especially when mudflows emerge from canyons with little or no warning and spread over populated areas. Mudflows are also common on the slopes of volcanoes; these are the largest and most destructive. As you recall, the town of Herculaneum near Mount Vesuvius was destroyed by a mudflow. In past history, mudflows also occurred along the coastal strip of volcanoes in northwest United States and have most recently occurred on Mount St. Helens.

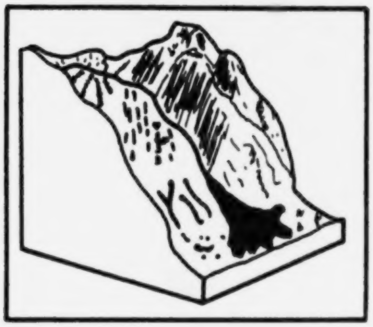


Figure 15.4. An illustration of a mudflow (represented in black) as it emerges from a canyon.

C. Landslides: In this type of mass-wasting, the movement is usually swift, involving the rapid sliding of large, unconsolidated soil and bedrock. The movement is along a definite plane or some kind of gliding surface. Water may start a landslide, but it is not actively involved in the transportation.
   1. Slump: This is the downward slipping of large bodies (commonly intact) of rock debris, bounded underneath by a curved surface along which movement occurs. (See Figure 15.5) In the semiarid regions of the Colorado and Columbia Plateaus, hundreds of slump blocks can be found. Some are as large as 5 kilometers by 150 meters (3 mi by 500 ft). Slumping can occur where rock has been undercut (eroded at the bottom more quickly than the top), and it can move in a matter of seconds or gradually slip during a period of several weeks.

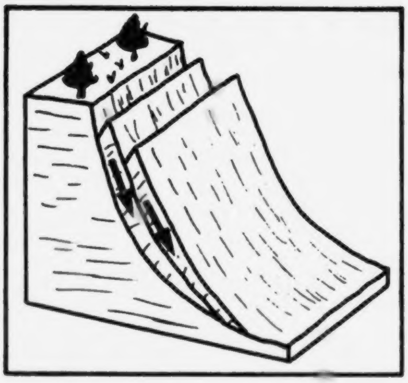


Figure 15.5. An illustration of slumping.

2. Debris slide: This is the rapid movement downward of wet, loose surface material over a surface of underlying bedrock. (See Figure 15.6) It occurs in dry to moderate climates, in areas of sparse vegetation, and in situations following heavy rains.

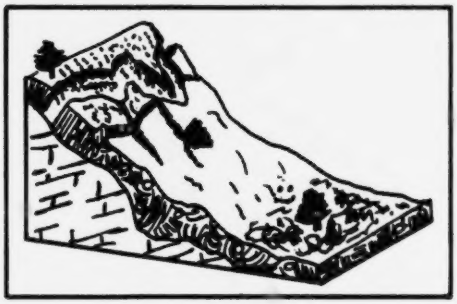


Figure 15.6. An illustration of debris slide.

3. Rockslide: A rockslide is the sliding of individual rocks down the slope of a bedding plane. (See Figure 15.7) Rockslides are common in high mountain ranges that have steep rock walls. The danger of rockslides is that they cannot usually be predicted. An earthquake shock set off the Madison rockslide at Hebgen Lake, Montana, in 1958.

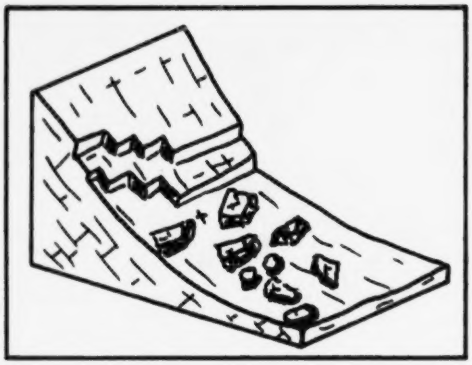


Figure 15.7. An illustration of a rockslide.

4. Rockfall: This is the free falling of rocks from a nearly vertical cliff. (See Figure 15.8) It is the most rapid of all landslides, and the debris ranges in size from large to small fragments. The debris, of course, simply accumulates at the base of the cliff.

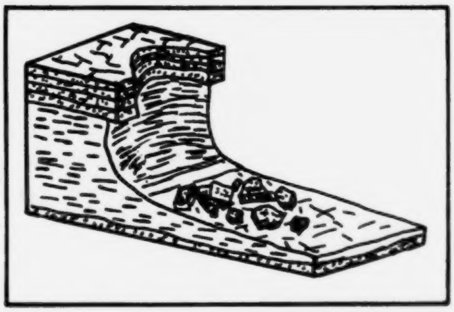


Figure 15.8. An illustration of a rockfall.

III. Sediment deposited by mass-wasting: Material that has been loosened from the side of a cliff or slope and has accumulated at the composes the sediment deposited by mass-wasting.
   A. Colluvium: This is anything that is deposited by mass-wasting. It tends to be a jumbled mess, angular in shape.
   B. Talus: Although technically a type of colluvium, talus is specifically the slide rock (rock involved in mass-wasting). Ravines tend to funnel the slide rock into the shape of aprons or cones called talus cones. (See Figure 15.9) Finer particles compose the top part of the cone, while coarser particles are found at the bottom.

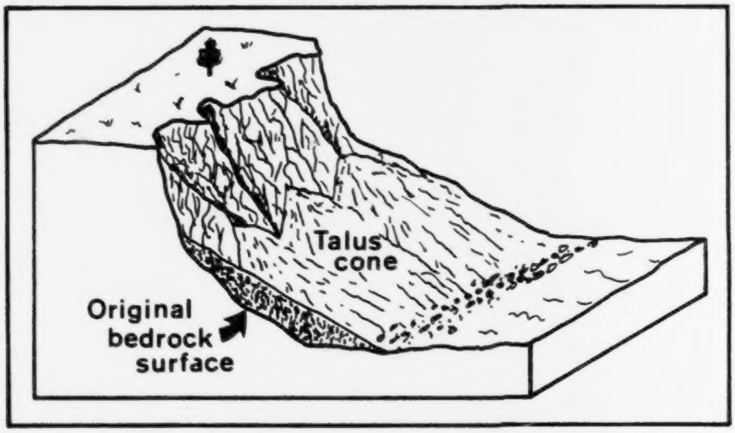


Figure 15.9. An illustration of talus cones.

IV. Factors that influence mass-wasting: Gravity is a constant influence on the behavior of rock debris involved in mass-wasting. In addition to its continuous influence, there are several other factors that occasionally affect mass-wasting.
   A. Slope: The greater the degree of slope, the more easily mass-wasting can occur because of the greater pull. Slopes tend to have less stability, also.

B. Precipitation: The amount of rainfall is a major factor contributing to flows. After heavy rains, the top material is mainly mud which flows downhill. Again, California comes to mind with its rains and devastating mudflows.

C. Earth material: As in weathering, the composition and structure of rock or sediment may have a great effect on mass wasting. Small, loose pieces move easier than large solid layers.

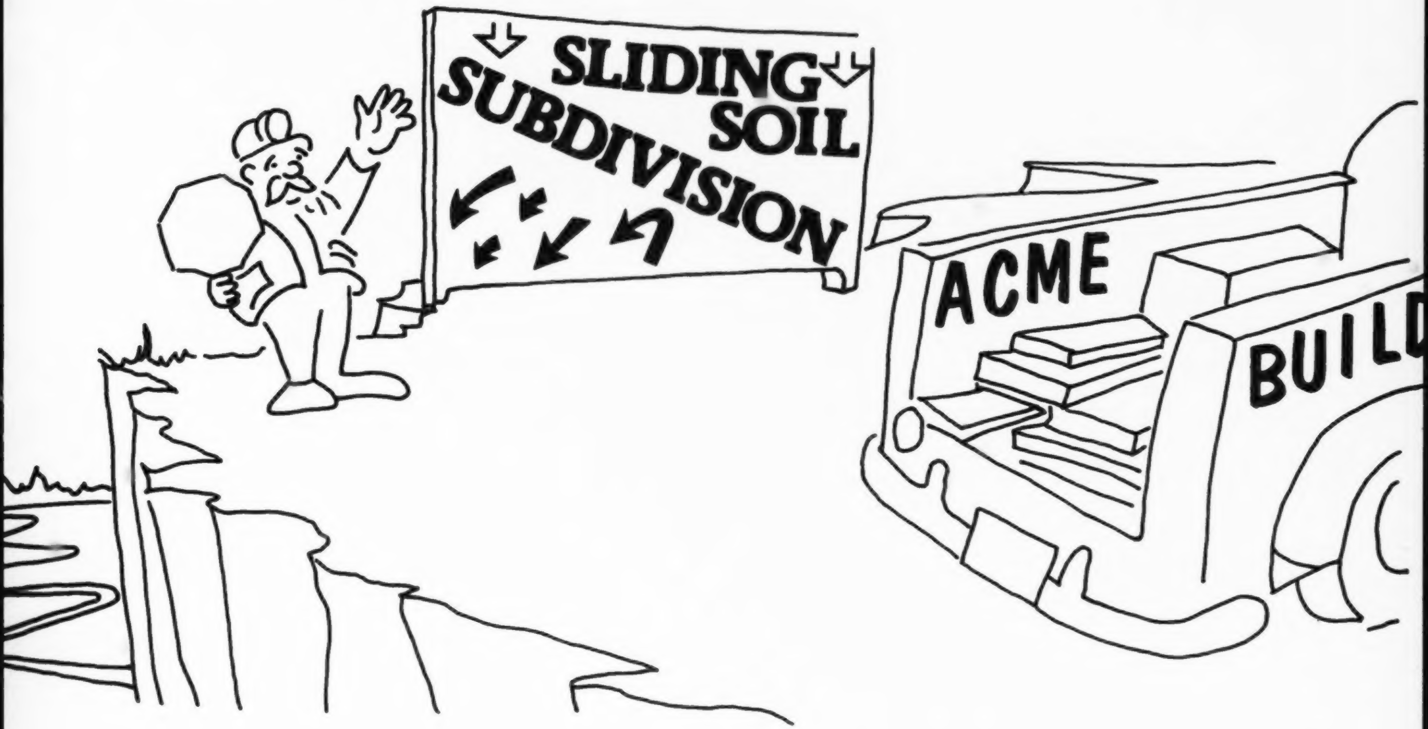
D. Plants: Plants play a large part in the way their roots tend to hold soil together. A slope with no vegetation will yield to gravity much more quickly than one covered with vegetation. California has recently been the scene of many mass-wasting problems because of heavy rains after several years of drought. Problems have been complicated by the fact that the drought destroyed thousands of kilometers of plant life.

E. Animals: These blessed creatures break up the soil, creating unstable slopes. Burrowing critters such as rodents and earthworms disturb the soil below the surface. Grazing animals trample the soil above the surface.

F. Streams: Erosion at the bottom of a slope or cliff by streams causes the bottom rock to erode away more quickly than the top (undercutting). This leaves the top with no support, leading to its collapse.

G. Earthquakes: Tremors dislodge material, making it more vulnerable to mass-wasting. The Yellowstone earthquake in 1958 was the trigger for the Hebgen landslide.

V. Hazards: The hazards of mass-wasting are numerous and are complicated by humanity's presence. While human beings can cause mass-wasting, a higher percentage of the problem rests with them trying to erect their creations in high risk areas with no regard to the possible geological behavior of the earth in nearby areas. Slumping can quickly eliminate roads, fences, and homes. And the list could go on and on. Large scale flows, falls, or slides can cause extensive damage to populated areas. Dam site selection can be tricky, simply because if the dam fails, the flooding of areas below the dam can be disastrous.



VI. Prediction: Scientists are unable to accurately predict the exact time that mass-wasting may occur. However, they are able to accurately identify high risk and low risk areas. It would therefore seem logical for human beings to simply avoid constructing and/or living in those high risk areas. Unfortunately, there is a little voice heard by most humans (a very unwise, unscientific little voice) that says, "Go ahead, and live here, human! It cannot happen to you!" The high risk dweller would be wise, since mass-wasting prediction is not possible, to listen to the Chinese. (Where have you heard this before?) Lower animals have odd predisaster behavior. Cattle leave the slopes before slides. Other animals become very nervous. Perhaps their instincts have substance.

VII. Summary: The nature of the earth's crust is such that there are always slopes of bedrock and regolith. The physics of all matter states that the pull of gravity never stops. Thus, the threat of mass-wasting is nearly always present, from the mini-slumping seen along stream banks to the maxi-mudslides or landslides that bury the helpless that happen to be in the wrong place at the wrong time. Mass-wasting is one of the ongoing processes that level our land. It is through geological education that we can hopefully live in peaceful harmony with this process instead of being leveled by it.

SEE ACTIVITY 15.1

SEE ACTIVITY 15.2

Chapter 15: Problems and Questions

1. Compare and contrast the eight (8) different types of mass-wasting.

2. Discuss the sediment deposited by mass-wasting.

3. Discuss three (3) environmental problems associated with mass-wasting.

4. Discuss each of the seven (7) factors which influence the rate of mass-wasting.

Unit V: External Processes

CHAPTER 16: Groundwater

- I. Introduction

- II. Water Cycle

- III. Sources of Groundwater
  - A. Juvenile Water
  - B. Connate Water
  - C. Meteoric Water

- IV. Geology of Groundwater
  - A. Myth Versus Reality
  - B. Factors Affecting Groundwater
    - 1. Rock Characteristics
      - a) Porosity
      - b) Permeability
    - 2. Precipitation
    - 3. Slope
  - C. Water Table
    - 1. Zone of Aeration
    - 2. Zone of Saturation
    - 3. Fluctuations in the Water Table
    - 4. Perched Water Table
    - 5. Artesian System
      - a) Sandwiched by Impermeable Beds
      - b) Inclined Beds
      - c) Sufficient Rainfall
      - d) Examples
        - (1) Great Plains
        - (2) Atlantic and Gulf Coastal Plains
  - D. Natural Surface Expressions of Groundwater
    - 1. Springs
    - 2. Lakes
      - a) Dammed Lakes
      - b) Fault Valley Lakes
      - c) Volcanic Crater Lakes
      - d) Sinkhole Lakes
      - e) Glacier-formed Lakes
      - f) Oxbow Lakes
    - 3. Swamps
  - E. Human-made Surface Expressions of Groundwater
    - 1. Pump Well (Water Table Well)
    - 2. Artesian Well

- V. Groundwater Erosion
  - A. Non-Solution Caves
    - 1. Shelter Caves
    - 2. Sea Caves
    - 3. Lava Caves

- B. Solution Caves
  - 1. Regional Characteristics
  - 2. Solution Process
  - 3. Stages of Cavern Development
  - 4. Secondary Deposits
    - a) Stalactites
    - b) Stalagmites
    - c) Columns
    - d) Curtains or Drapery
    - e) Flowstone
    - f) Rimstone
    - g) Helictites
  - 5. Other Secondary Features
    - a) Cave Fill
    - b) Breakdown
    - c) Domepits
    - d) Scallops
- C. Karst Topography
  - 1. Factors Influencing Development
  - 2. Erosion Cycle
    - a) Initial Development
    - b) Intermediate Development
    - c) Final Development
  - 3. Karst Locations
    - a) United States
    - b) World

VI. Groundwater Benefits

VII. Groundwater Problems
- A. Pollution
  - 1. Septic Tanks
  - 2. Holding Ponds and Lagoons
  - 3. Contaminated Streams
  - 4. Land Disposal of Wastes
- B. Surface Collapse
- C. Water Table Fluctuation
- D. Subsidence
- E. Salt Water Invasion

VIII. Summary

Related Activities

Vocabulary

Identify Karst features on topographic maps.

Problems and questions

Groundwater Geo Facts

If the water cycle were to end, the land-forming work that is done by water would cease, and the earth's crust would remain nearly changeless.

Ninety-five percent of all fresh water on earth is groundwater.

There are 25,000 water witchers in the United States.

Water at great depths may take tens to hundreds of thousands of years to pass through an aquifer. Some water is completely stagnant.

Below the water table, to a depth of less than half a kilometer in land areas of the earth's crust, there are about 4,166,667 cubic kilometers (1,000,000 mi^3) of groundwater. If all the groundwater in North America were brought to the surface, it would cover the land to a depth of over 254 centimeters (100 in).

Groundwater in shallow to moderately deep zones may remain underground from a few hours to one hundred years or longer.

No rock is completely impermeable to water if given enough time.

Removal of large amounts of groundwater has caused serious subsidence problems in such towns as Las Vegas, Nevada; San Jose, California; and Houston, Texas.

There is 35 times as much groundwater (at depths less than 0.8 kilometers) than that contained in all the fresh water lakes and streams in the United States.

Chapter 16: Word List

Tunneled Terms

Aquifer
Artesian system
Artesian well
Blind valley
Breakdown
Cave
Cave fill
Collapse sink
Column
Cone of depression
Connate water
Curtain
Dammed lake
Doline
Domepit
Dripstone
Fault valley lake
Flowstone
Geyser
Glacier-formed lake
Groundwater
Helictite
Hot spring
Hum
Impermeable
Juvenile water
Karst topography
Karst valley
Karst window
Lake
Lava cave
Meteoric water
Oxbow lake
Perched water table
Permeability
Porosity
Pump well
Rimstone dam
Sandstone cave
Scallops
Sink
Sinkhole
Sinkhole pond
Soda straw stalactite
Solution cave
Speleothem
Speleologist
Spring
Stalactite
Stalagmite
Swamp
Transpiration
Volcanic crater lake
Water cycle
Water table
Well
Zone of aeration
Zone of saturation
Zee-end

Straight Terms

Adjacent
Aerated
Alluvial
Cavity
Cylinder
Fluctuation
Infiltration
Juvenile
Pendent
Penetrate
Perch
Residual
Sentinel
Subsidence
Traverse
Ventilated
Void

UNIT V: EXTERNAL PROCESSES

Chapter 16: Groundwater

I. Introduction: Groundwater is simply that water which is out of sight, underground. It fills cracks and other openings in beds of rock and unconsolidated material in the lithosphere. It is that part of precipitation which seeps down through the soils to eventually provide us with a large source of water from wells. Although streams and lakes are good water sources, groundwater as an unseen source is sizable throughout much of the Midwest. It has advantages over stream and lake water in that underground storage systems prevent evaporation and provide better protection against contamination. Frequently, it is a resource of particular importance because of its quality and quantity.

II. Water cycle: (The following is adapted from "the hydrologic cycle," a USGS publication.) The water cycle is the endless circulation of water from the oceans, into the atmosphere, down upon the land, and back to the sea. (See Figure 16.1) Through the ages, little water has been added or lost since the first clouds formed and the first rains fell. Although the water cycle has no beginning nor end, it is convenient to start our discussion at the major storage area, the oceans. Liquid water from the surface of the oceans is evaporated into the atmosphere as water vapor, a gas. The sun provides the energy for this evaporative process. The water vapor in the air is lifted and cooled, eventually condensing to fall as precipitation either back on the oceans or on land areas. Precipitation may fall in the form of rain, snow, sleet, or hail. Much of this precipitation evaporates, sometimes even before it reaches the surface, so that it circles directly back to the atmosphere; it may once more become precipitation, but it is lost for immediate beneficial uses by human beings. Another large portion is used by vegetation and transpired back to the atmosphere. Transpiration is the process whereby plants breathe moisture through their surfaces. Together, evaporation and transpiration account for about three-fourths of the original precipitation, which can be considered a bypass in the water cycle. The remaining part of the water that falls as precipitation moves over and through the land areas of the earth, draining finally into channels that flow again to the ocean. Only this portion is available temporarily for humanity's use, held for varying times in streams, lakes, glaciers, or in layers of the earth's crust.

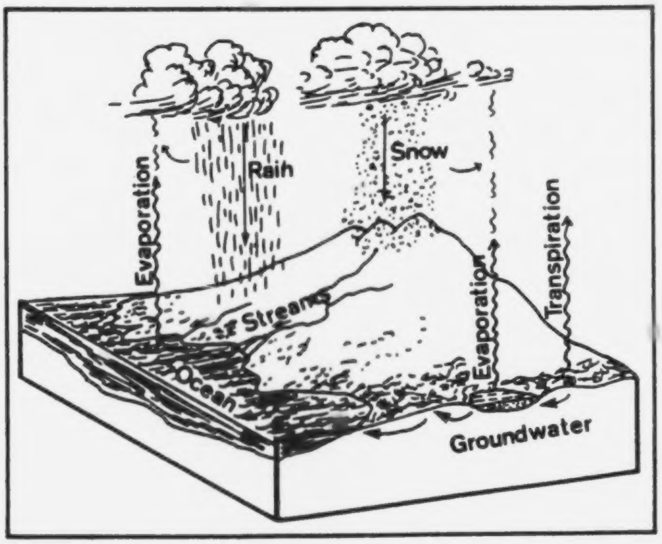
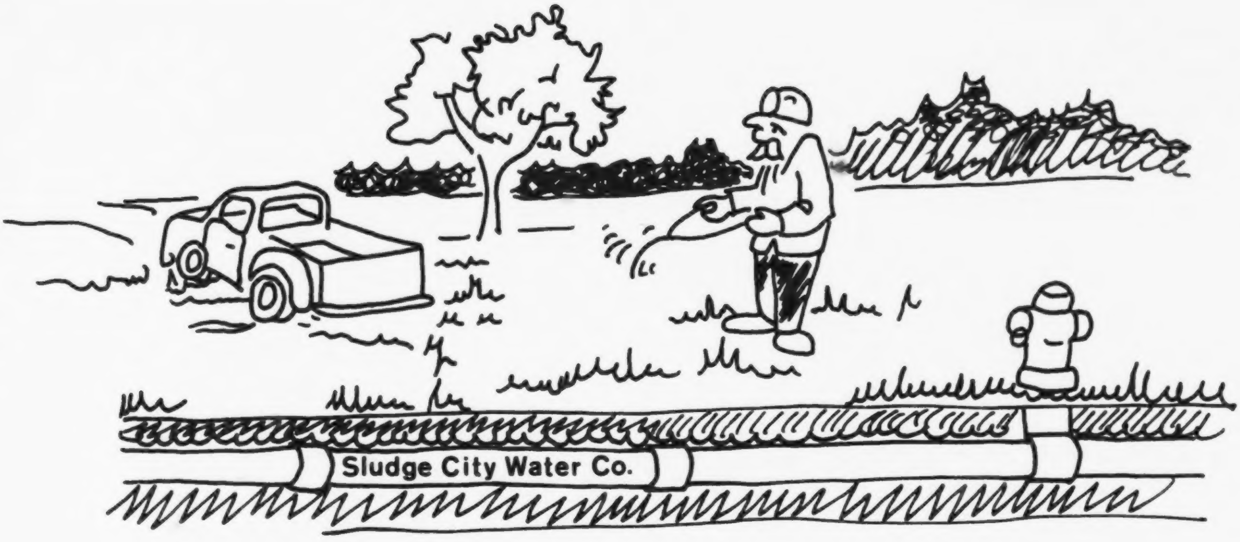


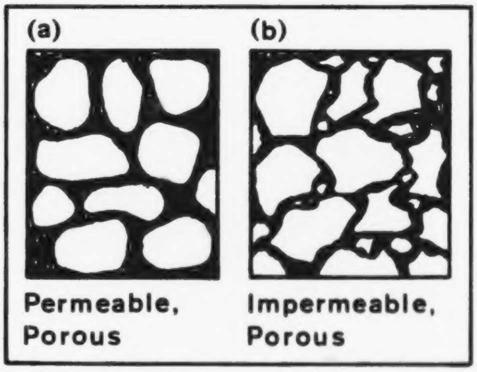
Figure 16.1. A general water cycle is illustrated. Evaporation can take place as the rain or snow fall.

III. Sources of groundwater: There are three sources of groundwater.
   A. Juvenile water: As you read in the volcano chapter, water is a by-product of volcanic activity. This water is called juvenile water, because it is just beginning to circulate freely.
   B. Connate water: As sediment is being deposited, water becomes trapped within the deposit and is called connate water. Because many sedimentary rocks were deposited beneath sea water, connate water is frequently salty.
   C. Meteoric water: This is water that falls from the sky in some form of precipitation. It is the major source of groundwater. Rain or snow can evaporate while falling, run off in streams, or soak into the ground and thus supply groundwater. Groundwater is more abundant in the northern part of Illinois partly because the surface runoff is less, owing to a more level topography.

IV. Geology of groundwater: Strange as it may seem, there are many controls determining the future of water once it becomes groundwater.
   A. Myth Versus Reality: As is common with subjects that cannot actually be observed, there are many misconceptions concerning groundwater.
      1. Myth: Groundwater is often found in underground streams and lakes.
      Fact: Bodies of groundwater do not usually resemble surface bodies of water. Instead, groundwater is found in interconnected openings of rock formations or gravel deposits.
      2. Myth: Water rushes so fast underground, it is possible to hear it.
      Fact: Nearly always, groundwater flows from an approximate speed of 1.5 meters (5 ft) a day to 1.5 meters (5 ft) a year. (That is too slow to hear, Gang!) Compare that speed to the average speed of surface water at 32 kilometers per hour (20 mph).
      3. Myth: Groundwater travels thousands of kilometers through the earth.
      Fact: Most groundwater is removed from the ground near the vicinity it first appeared.
      4. Myth: No relationship exists between groundwater and surface water.
      Fact: Groundwater is the source of much of the water for streams. Lakes and swamps merely reflect the presence of the water table at the earth's surface.
      5. Myth: Groundwater is not a significant water source.
      Fact: The amount of groundwater in storage is about 35 times greater than our present surface supply of fresh water.
      6. Myth: If groundwater is removed from the earth, it is never returned.
      Fact: Groundwater is replaced by water seeping down from the surface of the ground.
      7. Myth: Groundwater is mysterious and magical.
      Fact: Hogwash! It is governed by natural laws, and therefore, its behavior is predictable.
      8. Myth: A water witcher (dowser or diviner) possesses power that enables him/her to discover "underground streams." A forked stick held by the water witcher will dip violently when an underground stream is crossed, thus indicating an excellent site to dig a well.
      Fact: There is no scientific basis for the success of a water witcher. Underground streams do not exist, but the probability of success is high because rock formations containing water are widespread.


Sludge City Water Co.

B. Factors affecting groundwater: Groundwater does not travel with equal vigor through all types of rock. There are three factors that control groundwater behavior.
  1. Rock characteristics: The qualities of the rock determine variations in groundwater movement.
     a) Porosity: Porosity is the percentage of the material (rock or regolith) that is void (has empty spaces). (See Figure 16.2) For example, a very porous rock is one that contains a relatively large proportion of open space, regardless of the size of the spaces. Porosity gives an indication of the ability of a rock to hold liquid in storage. It is determined by the shape of the grains, their sorting and packing, and the degree of cementation. Sandstones and conglomerates are usually quite porous.



Permeable, Porous

Impermeable, Porous

Figure 16.2. (a) illustrates porosity; the dark areas represent the space through which water can travel. (b) illustrates some porous material that is not permeable.

b) Permeability: Permeability is the ability of regolith or rock to transmit a liquid. It is necessary for a material to be porous if it is also to be permeable. However, the fact that a rock is porous does not necessarily mean that it is permeable. (See Figure 16.3) For example, shale contains many little cavities and is therefore very porous. The spaces are not interconnected, though, so liquid cannot move freely through the shale; it is known to be impermeable. Some permeable rocks include imperfectly cemented sandstone and certain kinds of limestone in which solution has created open spaces. An aquifer is a formation of permeable material through which groundwater travels into wells and springs. (See Figure 16.3) It usually has an impermeable layer such as shale below it. Depending upon the formation, the water-yielding capacity of aquifers varies greatly. Usually aquifers are regularly refilled by rainfall occurring directly onto the soil surface or by infiltration from adjacent streams or lakes.

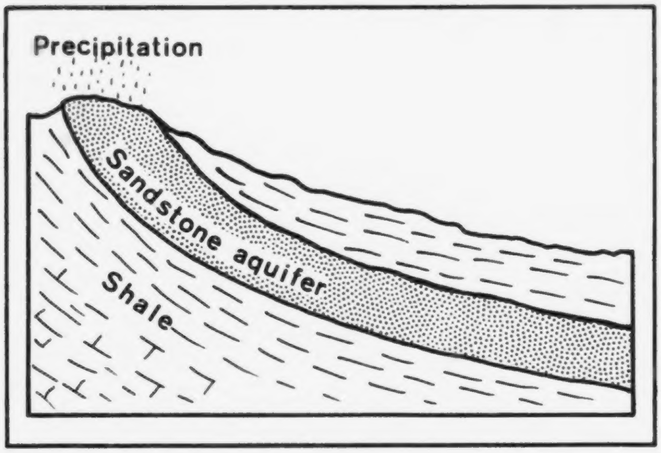


Figure 16.3. An illustration of a sandstone aquifer.

2. Precipitation: Another factor affecting groundwater is the amount of rainfall. During the summer of 1977, much of the United States suffered drought conditions, thereby reducing the amount of groundwater. (The water removed from the ground was not replaced by rainfall.) Many wells went dry because they were not deep enough to penetrate the lowered water table.
3. Slope: The slope of the earth's surface influences the amount of water that can soak into the ground. A relatively flat surface will hold much of the rainfall until it can filter into the earth, while a slope will cause more runoff of water immediately into a stream.

C. Water table: There is a subsurface zone in which all of the openings in the material are filled with water. The upper surface of this zone is the water table. The water table is important, because when digging a well, it is necessary to penetrate the water table to provide a dependable well. The topography of the water table tends to reflect the contours of the ground surface, rising under hills and sloping down under valleys. From information provided by people who have dug or drilled thousands of wells, a profile of various subsurface zones has been discovered.

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1. Zone of aeration: The zone of aeration is the zone of regolith or bedrock in which the open spaces are partially filled with air and water. This is the zone where weathering is active. It can be various thicknesses, ranging from zero where the water table is exposed in a marsh or lake, to a few centimeters thick, to several hundred meters thick in hilly or mountainous areas. (See Figure 16.4)

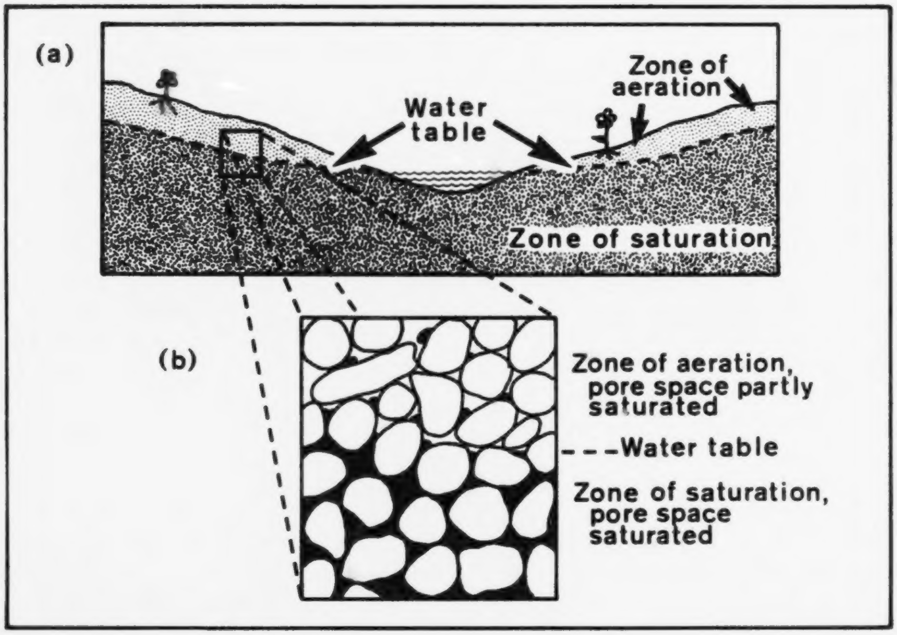
(a)
Zone of aeration
Water table
Zone of saturation
(b)
Zone of aeration, pore space partly saturated
---Water table
Zone of saturation, pore space saturated

Figure 16.4. (a) illustrates the water table in relation to the zone of aeration and the zone of saturation. Note that when water appears on the surface, there is no zone of aeration. (a) illustrates a microscopic view of the zones of aeration and saturation.

2. Zone of saturation: Beneath the zone of saturation is a zone in which all of the spaces are completely filled with water--the zone of saturation. (See Figure 16.5) The water table is the upper surface of the zone of saturation. This zone can extend to considerable depths. Under natural conditions, its thickness varies according to the amount of rainfall.

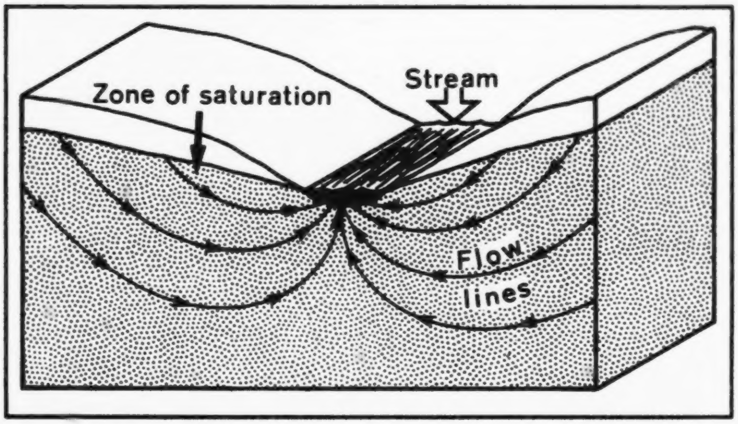

Figure 16.5. As rainfall strikes the ground surface, it seeps through the zone of aeration, traveling down through the zone of saturation. The nature of groundwater movement is such that it then curves back up to enter the stream. This explains why some streams can continue to flow during times of low rainfall.

3. Fluctuations in the water table: Figure 16.5 illustrates the movement of groundwater in uniformly permeable rock material. As you can see, the water table roughly reflects the ground surface above it. In times of drought, the water table tends to flatten and then sink to a lower level. Depending upon the elevation of the stream bed, it is possible for the stream to dry up when the water table becomes low enough. (See Figure 16.6) Another possible fluctuation in the water table occurs when lifting water from a well. This results in the lowering of the water level around the well, creating a cone of depression (a cone-shaped depression in the water table just immediately surrounding a well). As water is withdrawn from the well, the nearby groundwater cannot travel rapidly enough to replace the water removed. That is why a cone of depression forms rather than the entire water table level becoming considerably lower. (See Figures 16.6 and 16.7)
4. Perched water table: Occasionally, a situation exists in which an impermeable layer, such as shale, exists within the zone of aeration. As a result, groundwater is trapped above the impermeable layer and cannot reach the main water table. A perched water table is thus formed. (See Figure 16.8) If the perched water table reaches the side of a valley, it slowly seeps out, forming a spring. It can be an important, though local, source of water.

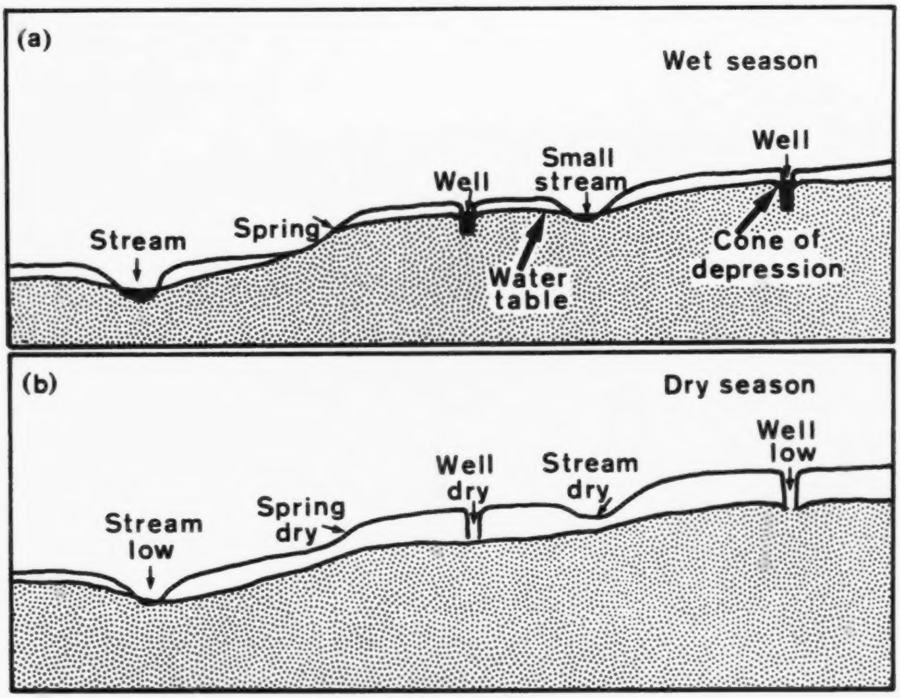
(a)
Wet season
Well
Small stream
Well
Stream
Spring
Water table
Cone of depression
(b)
Dry season
Well low
Well dry
Stream dry
Spring dry
Stream low

Figure 16.6. (a) illustrates the water table during the wet season. (b) represents the water table conditions during a dry season.

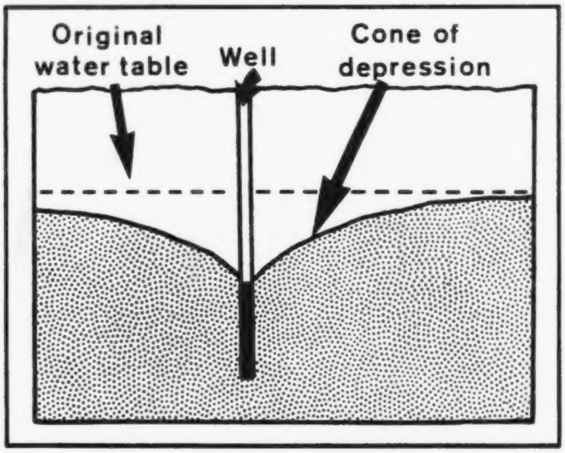
Original water table
Well
Cone of depression

Figure 16.7. A close-up of a cone of depression. Note the difference in the original water table level and the water table after groundwater was removed from the well.

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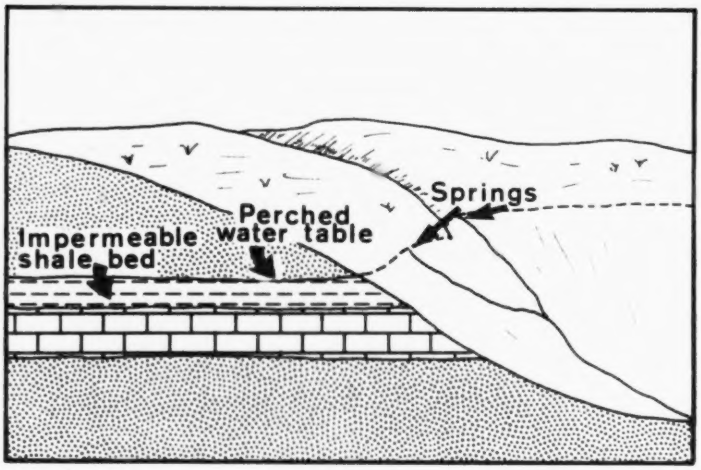

Springs
Perched water table
Impermeable shale bed

Figure 16.8. A perched water table with an impermeable shale layer preventing the water from seeping farther down.

5. Artesian system: An artesian system is an aquifer through which water flows while under abnormally high pressure. (See Figure 16.9) The water in the aquifer acts much like water under pressure in a pipe, because the weight of the water at higher levels in the aquifer exerts pressure on the water in a confined area. Three geologic conditions must exist in order to form an artesian system.
   a) Sandwiched by impermeable beds: An aquifer must be sandwiched in between two impermeable beds, such as shale, in order to keep the pressure high.
   b) Inclined beds: The beds must be inclined or tilted, and the upper end must be exposed at the ground surface for rainfall to feed the aquifer.
   c) Sufficient rainfall: There must be sufficient rainfall in the outcrop area to supply an adequate amount of water.

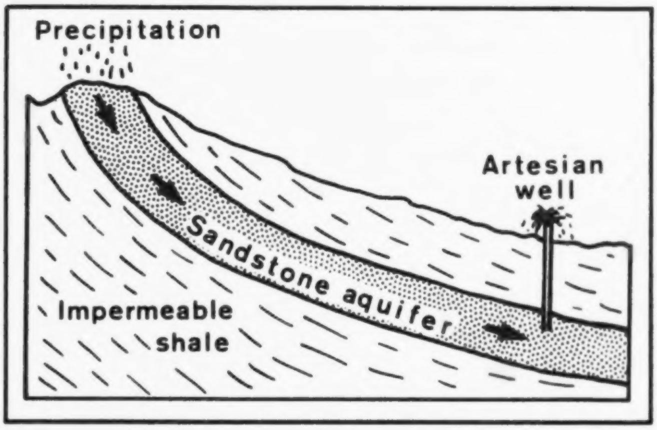

Precipitation
Artesian well
Sandstone aquifer
Impermeable shale

Figure 16.9. An illustration of an artesian aquifer with all of the conditions favorable for its occurrence. The arrows indicate the direction of groundwater movement.

d) Examples: There are several well-known artesian systems in the United States.

   (1) Great Plains: The nearly horizontal Dakota sandstone underlies the north-central states, but it is warped up along the eastern front of the Rocky Mountains. The artesian water system receives its source of water in the Black Hills and Rocky Mountains. (See Figure 16.10)

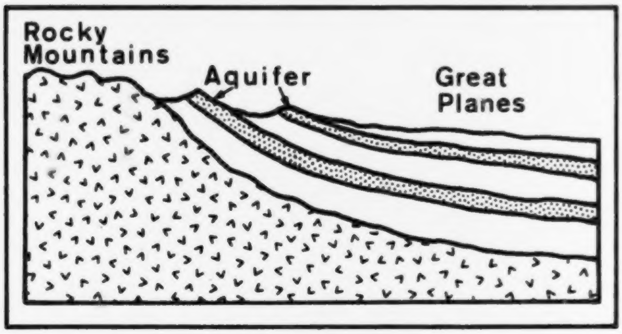


Figure 16.10. The Great Plains are underlain by permeable Cretaceous sandstones that warp up along the Rockies where they receive their water supply.

   (2) Atlantic and Gulf Coastal Plains: In this situation, permeable sandstone and limestone beds alternate with impermeable clay, and they dip toward the sea. Water enters the beds where they are exposed at the surface and is confined to form a large artesian system. (See Figure 16.11)

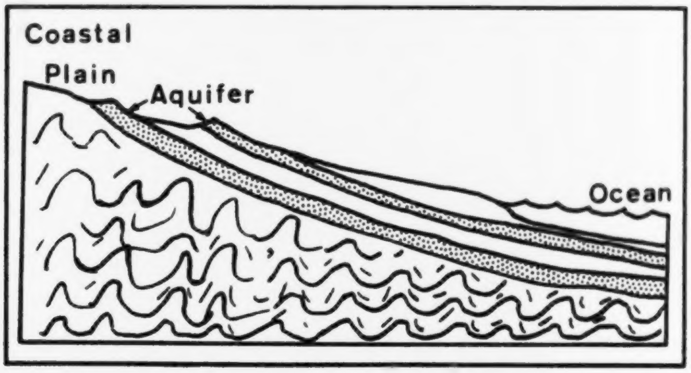


Figure 16.11. An illustration of the artesian systems located under the Coastal Plains. They are underlain by rocks that dip toward the ocean. Water enters the aquifers where they are exposed to form the artesian systems.

D. Natural surface expressions of groundwater: Although groundwater is beneath the earth's surface for the most part, under certain circumstances, it surfaces for various reasons and in different forms.

1. Springs: A spring is any natural discharge of water from rock or soil onto the surface of land or into a body of surface water. (See Figure 16.8) The daily yields of springs can vary from a few liters per day to yields capable of supplying the needs of a large metropolitan area. (See Table 16.1) The Missouri Ozarks comprise one of the nation's greatest concentrations of springs because of the presence of carbonate rocks. (In fact, the springs in Missouri once played a major role in the settlement and development of the state.) While springs are commonly found in carbonate rocks, they can be found in any permeable rock such as basalt and sandstone. As was discussed in the volcano chapter, a geyser is a hot spring that intermittently erupts. The geyser must be near a substantial source of heat such as cooling magma.
2. Lakes: A lake is a standing body of water. In most cases, the lake bottom is below the water table. Exceptions include lakes in perched water tables, those in shallow basins that receive large quantities of surface water, and those in volcanic craters. There are several different kinds of lakes, each formed in a dissimilar manner.

Table 16.1. Some of the largest springs in the United States.

Name of Spring	Location	Average Discharge*	Type of Aquifer
Big Spring	South-central Missouri	12 (427 ft^3)	Limestone
Silver Springs	Florida	23 (813 ft^3)	Limestone
Malad Springs	Idaho	**28 (1,000 ft^3)	Basalt
Rainbow Springs	Florida	20 (700 ft^3)	Limestone
Giant Springs	Montana	17 (600 ft^3)	Sandstone

*In cubic meters per second.
**This is an approximate figure because the spring consists of many outlets along the Snake River.

a) Dammed lakes: These form when the stream valley is blocked by mass-wasting of all types, lava flows, or glacial deposits to form a lake. A mudflow of volcanic ash formed Lake San Cristobal, near Lake City, Colorado.
b) Fault valley lakes: Water can accumulate in grabens to form some of the largest lakes in the world. Lake Tahoe is a famous graben lake on the border of Nevada and California.
c) Volcanic crater lakes: Cooled lava can seal the craters of volcanic cones so that they hold water. Crater Lake, Oregon, is one of the best known examples.
d) Sinkhole lakes: In areas containing limestone bedrock, dissolved limestone results in depressions on the earth's surface. When water accumulates in these depressions, they are called sinkhole lakes. In

central Florida, nearly all of the lakes are of this type. In fact, within the city limits of Orlando, Florida, there are 30 sinkhole lakes.

e) Glacier-formed lakes: Glaciers scour out basins in bedrock, block off valleys, and in other various ways are responsible for more lakes than all of the other causes combined. Minnesota and Maine are dotted by thousands of lakes caused by glaciers. The Great Lakes can thank glaciers for their existence.

f) Oxbow lakes: These are lakes that form in abandoned stream channels after they change their course.

3. Swamps: A swamp is a low area of wet, spongy land where the water table barely reaches the ground surface. Famous swamps in the United States are the Everglades of Florida, and the Dismal Swamps of North Carolina and Virginia.

E. Human-made surface expressions of groundwater: A well is a human-made hole drilled through the zone of aeration into the zone of saturation. Water flows through the pores and into the well, up to the level of the water table. The water must then be brought to the surface by pump, by bucket (Jack and Jill's way), or by artesian pressure.

1. Pump well (water table well): Water is forced up the well by a motor-driven pump or a pump driven by a windmill. Most pumps for large water supplies are driven by electricity, gasoline, or fuel oil. Pumping always produces a cone of depression, because it removes the water more quickly than it is replenished.
2. Artesian well: As was stated before, artesian water is under pressure. When a well penetrates an artesian aquifer, the pressure forces the water to rise in the well above the top of the aquifer. (See Figure 16.12) Many of the first artesian wells in northern Illinois once flowed freely at the ground surface without pumping. As more wells were drilled, the pressure was reduced, so that now the water no longer rises as high and must be pumped to the surface. It be pointed out here that an artesian well does not have to be deep, and, except for a few wells, the flow may not rise to the surface. It simply depends upon the location of the well in respect to the aquifer.

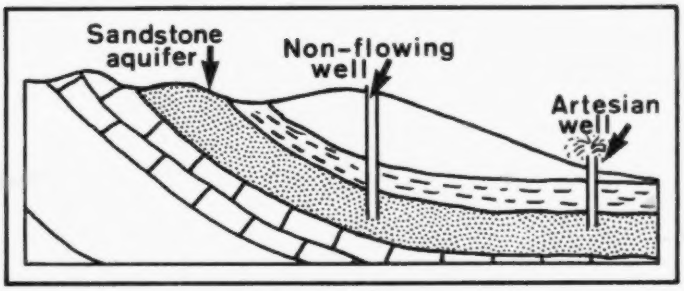


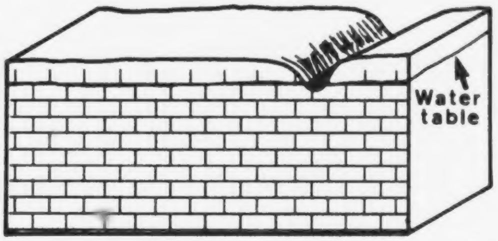
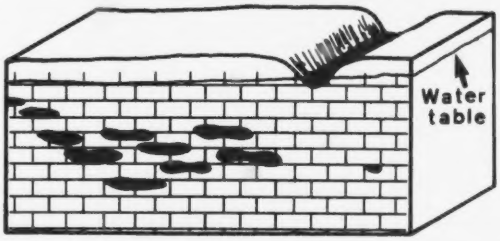
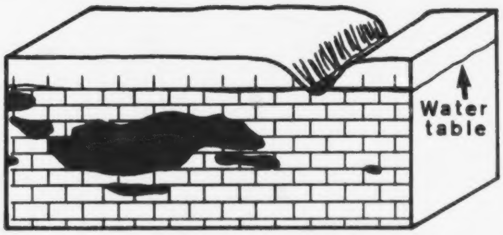
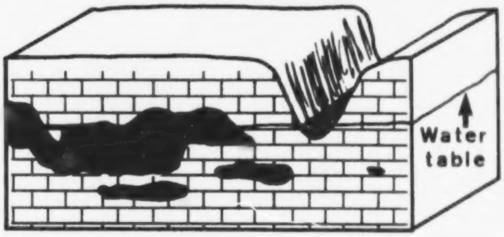
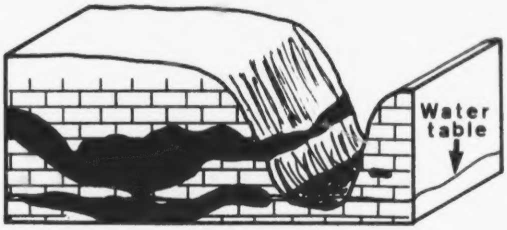
Figure 16.12. In order for an artesian well to flow from its own pressure, the top of the well must be lower than the highest point of the aquifer.

V. Groundwater erosion: Because groundwater moves so slowly, it is not usually capable of much physical weathering. However, through the process of chemical weathering, groundwater is capable of dissolving large quantities of rock and carrying it away in solution. The best known feature associated with groundwater erosion is the solution cave. First, a quick summary of the non-solution created caves, then on with solution caves. Why spend most of your time on solution caves? It is because they are by far the most abundant and largest type of cave.

A. Non-solution caves: A cave has been defined as a natural cavity large enough for a human to enter. Not a great definition, especially when humans come in a variety of shapes and sizes, but it is a place to start. There are four main cave types, based on origin, three of them are not related to groundwater erosion solution.
   1. Shelter caves: These caves are actually nothing more than an overhanging cliff or bluff face that offers some protection from the weather. The name "shelter" comes from the fact that many early cultures used these caves as living quarters. These caves are usually of much more interest to archeologists and anthropologists than to geologists.
   2. Sea caves: As the name implies, this type of cave is found along the shorelines of oceans (ancient and present). They are created by wave action and sediment eroding cavities in weakened rock at the water's edge. Sea caves are most common along the coasts of the Pacific Northwest and northern New England.
   3. Lava caves (tubes): As discussed in Chapter 11, VI B; lava caves form when the outer surface of a lava flow hardens, while the molten lava beneath flows out, thus creating a cavity or tube. Lava caves occur mainly in the Cascade Mountains and in Hawaii.

B. Solution caves: These are caves formed by groundwater erosion of soluble rock. Solution caves make up the vast majority of caves in the world, as well as being the deepest and longest caves in the world. Nice and short, right! Wrong, this goes on for pages and pages.
   1. Regional characteristics: As with any geological process, certain physical characteristics must be in place before cavern development can occur.
      a) Soluble bedrock such as limestone, dolostone, or marble is near or at the surface.
      b) The bedrock is dense, highly jointed, and thin bedded. Why?
      c) A climate that is fairly warm and moist.
      d) Area streams that have downcut or are downcutting, so the solution passages can be drained.
   2. Solution process: Recall from the weathering chapter that as rain falls, it chemically combines with carbon dioxide in the air or soil to form a weak carbonic acid. After the rain has entered the ground and becomes groundwater, it is capable of effective chemical weathering through solution. This process begins with groundwater trickling down through joints, faults, or bedding planes, dissolving soluble rock.
   3. Stages of cavern development: Groundwater continues to seep down until it reaches the water table. It is at this level and deeper, in the zone of saturation, that carbonic acid works to form caves. (See Table 16.2) For hundreds of thousands of years, the water enlarges bedding planes, joints, cracks, and porous zones in the rock, many of them becoming crevices or even larger cavities. Eventually, master channels are developed in the zone of saturation. Later, sediment from erosion is carried into the caves, either partly or completely filling them. In more recent geologic time, either because the land has been uplifted or erosion of stream beds has lowered the water table, the water is drained from the caves. As water in the zone of aeration trickles through the caves, it washes away much of the earlier clay filling and restores the caves to their original size. It is at this point that secondary cave features develop.

Table 16.2. Stages of cave formation

	Initial stage
	Enlarging of joints below the water table.
	Formation of cavern below the water table; cave filled with sediment.
	Downcutting of stream and seasonal fluctuation of the water table; cave sediment begins to be washed away.
	Water table below cavern, and stream downcuts to form openings to the surface; speleothems develop.

4. Secondary deposits: The chemical process causing deposition of calcite is in reverse of the process of solution. Water in the zone of aeration dissolves some calcite as it trickles down through the limestone above the caves. It is still enriched with carbon dioxide upon reaching the ventilated caves. The carbon dioxide gas escapes from the water (just as it escapes from an opened bottle of soda pop). The acidity of the water is thereby reduced, the calcium

bicarbonate cannot remain in solution, and calcite is deposited as material called dripstone. The decorative dripstone features are called speleothems. They can only occur in well-ventilated areas; otherwise, the air is too saturated with carbon dioxide to hold any additional gas. There are several speleothems with which you may be familiar. Geologists, or more specifically, speleologists (scientists who study caves) use the term speleothem rather than the commonly heard term "formation," so there is no confusion about these features and rock formations, which are designated geological units of rock. (See Figure 16.13) (The following is adapted from "Geology of Caves," a USGS publication.)

a) Stalactites: These are structures that hang downward from the ceiling of the cave and are formed as drop after drop of water slowly trickles through cracks in the cave roof. As each drop of water hangs from the ceiling, it loses carbon dioxide and deposits a film of calcite. Successive drops add ring below ring, the water dripping through the hollow center of the rings, until a pendant-shaped cylinder forms. Tubular or "soda straw" stalactites grow in this way; most are fragile and have the diameter of a drop of water, but some reach a length of perhaps a meter or more. The large cone-shaped stalactites begin as these fragile tubes and then enlarge to become cones when enough water accumulates to flow along the outside of the "soda straws." Deposition of calcite on the outside of the tubes, most of which are near the ceiling and taper downward, results in the familiar cone shapes.

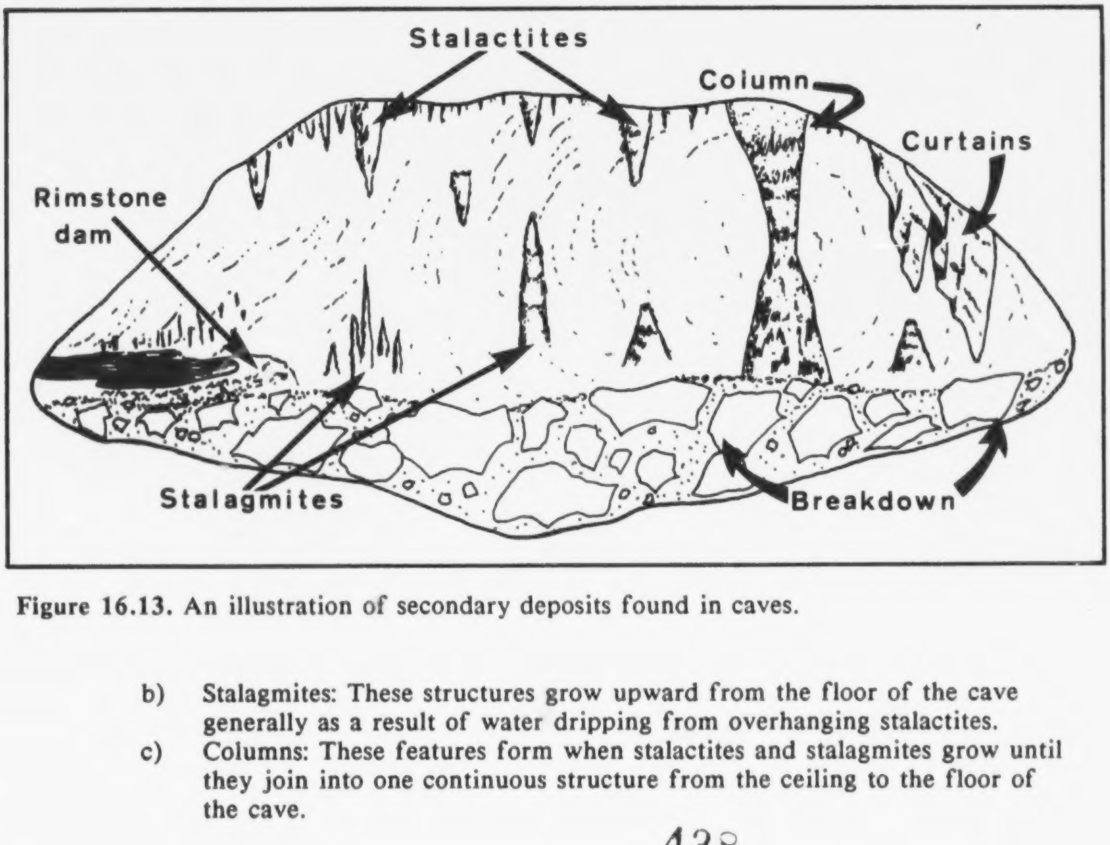


Figure 16.13. An illustration of secondary deposits found in caves.

b) Stalagmites: These structures grow upward from the floor of the cave generally as a result of water dripping from overhanging stalactites.

c) Columns: These features form when stalactites and stalagmites grow until they join into one continuous structure from the ceiling to the floor of the cave.

d) Curtains or drapery: These structures begin to form on an inclined ceiling when the drops of water trickle along a slope. Gradually a thin sheet of calcite grows downward from the ceiling and hangs in decorative folds like those seen on drapes.

e) Flowstone: Flowstone consists of sheets of calcite that are deposited on the walls or floor of the cave by running water.

f) Rimstone dams: These structures are raised, fence-like deposits of calcite that formed around rims of overflowing basins of water. They further dam streams to form larger pools of water.

g) Helictites: These are curiously twisted or spiraling cylinders or needles. They apparently develop when water seeps through the ceiling so slowly that slight chemical or physical changes can cause reorientation of the crystal structures of the calcite or gypsum.

5. Other secondary features: In addition to dripstone features, there are other features found in caves.

a) Cave fill: Most cave passages contain deposits of material that have been washed into the cave. This material, known as cave fill, varies from sand and clay to stratified gravel. The pebbles in these deposits are often highly polished and sometimes are as large as 15 centimeters (6 in) in diameter. Cave fills are particularly noteworthy because they contain materials that reflect a geologic history and a record of past climates of the surrounding area.

b) Breakdown: An accumulation of rock material produced by the collapse of the ceiling or walls of a cave is called breakdown. It may range in size from plates and chips to massive blocks. Most breakdown present in caves today appears to have occurred thousands of years ago. It is generally associated with the early history of cave development.

c) Domepits: A domepit is a vertical shaft created by the movement of groundwater downward along joints in the rock, thus dissolving the rock. Most domepits range from six meters (20 ft) to 60 meters (200 ft) in length. The largest one in the United States is in Fern Cave, Alabama, with a length of 133 meters (440 ft).

d) Scallops: Scallops are solution pockets found in cave stream beds, near the floor, and below a definite high-water line. They form only in caves by streams that entered caves late in their history.

C. Karst topography: Particular landforms eventually develop over areas of cavern development. These landforms constitute areas of karst topography and consist of thin soils, few or no surface streams, disappearing streams, and sunken holes. Such landforms are named after the Karst district of Yugoslavia, where this type of topography was first recognized.

1. Factors influencing development: If karst topography is to fully develop, four conditions are necessary.

a) Rock type: Soluble rock, preferably limestone because it is readily soluble, must be present at or near the surface.

b) Rock structure: The soluble rock must be dense, highly jointed, and preferably thinly bedded.

c) Major stream elevation: The major stream must be low enough to allow drainage of the soluble rock.

d) Climatic conditions: The region must have at least a moderate amount of rainfall.

2. Erosion cycle: Karst topography develops through a series of stages. (See Figure 16.14)

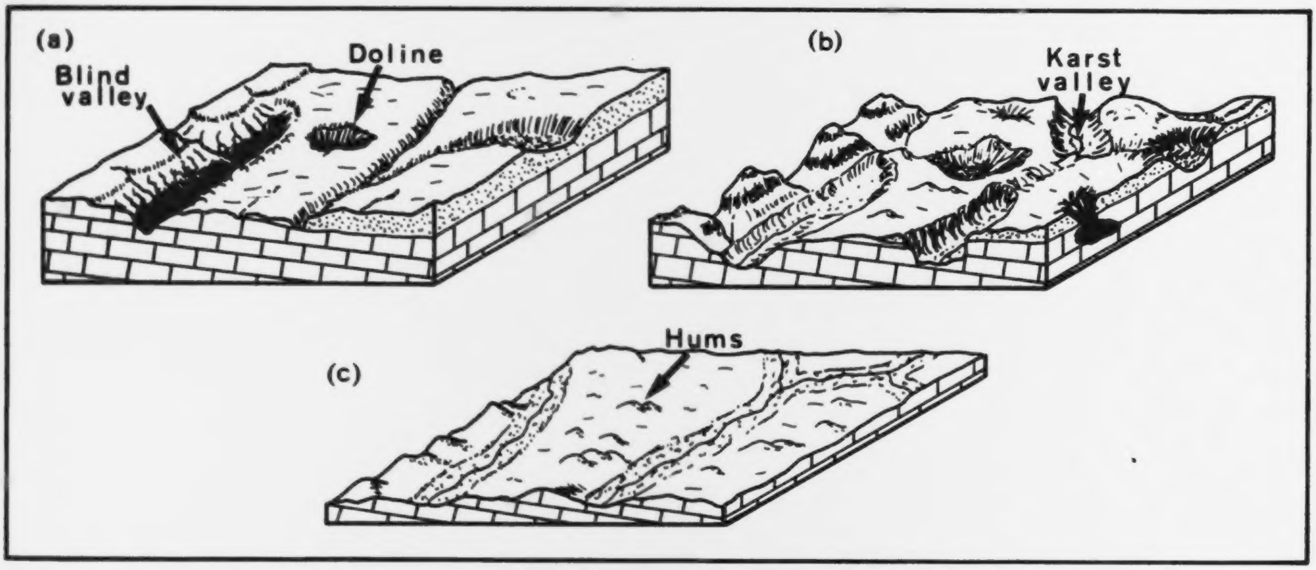


Figure 16.14. The karst cycle is shown in three progressive illustrations. (a) shows the initial development in which there are scattered sinkholes that continue to grow in size. (b) shows the intermediate development with larger and more sinkholes and karst valleys. A great deal of the surface has dissolved and disappeared, contributing to the presence of disappearing streams. (c) is the final development in which most of the limestone has been eliminated, leaving isolated hums.

a) Initial development: The main streams of an area erode their valleys to a deeper level, thereby lowering the water table. Groundwater then moves through the joints and bedding surfaces in the limestone, thus enlarging the opening which may eventually become caves. However, large caves do not exist at this stage. On the surface, depressions form that vary in depth from a few meters to a maximum of 31 meters (100 ft) or more. These depressions are called sinkholes. There are fundamentally two major kinds of sinkholes. The first is a doline which forms by the solution of limestone to create a gentle-sided sinkhole. In the initial development of karst topography, surface water frequently disappears into dolines. The second kind of sinkhole is a collapse sink. It is formed by the collapse of cave roofs. A collapse sink can be distinguished from a doline, because a collapse sink has steeper sides and has rock debris on its floor, while a doline has an accumulation of fine sediment. The surface opening of a sinkhole where water enters is called a sink or swallow hole. Dolines sometimes become clogged to the extent that they hold water and are called sinkhole ponds or lakes.

b) Intermediate development: It is during this stage that maximum underground drainage exists. Surface drainage is limited, with streams disappearing into sinks or blind valleys. A blind valley is a valley on the surface which is completely enclosed and has only subsurface drainage. In other words, a stream disappears into a sink at the closed end of a valley. The stream erodes its valley upstream. A karst valley, similar to a blind valley, is an isolated valley formed by the dissolving of rocks or collapse of caves and is surrounded by less soluble rocks, primarily rocks other than limestone. Caves form network patterns. This is the stage of maximum development. Sinkholes often open directly into horizontal underground passages through which one can see an underground stream and are called karst windows. Late in the intermediate stage, gulfs form which are enlarged sinkholes or karst windows with steep sides and rocky floors. Springs are common along major streams.

    c) Final development: Nearly all of the original limestone surface is dissolved. Surface drainage returns, and a few hums (residual hills also known as haystack hills) remain as reminders of an original limestone terrain.

3. Karst locations: Relatively large areas of Karst occur in many areas of the United States and throughout the world.
    a) United States: Areas include central Florida, the Great Valley of Virginia, and Tennessee, and the plateau regions of southern Indiana, central Kentucky, and north-central Tennessee.
    b) Some of the better known regions include the West Indies, Puerto Rico, England, Greece, southern France, and, of course, Yugoslavia.

VI. Groundwater benefits: Most groundwater is a relatively pure source of water. It is used for drinking water, for industrial purposes, for agriculture, and for wildlife. Areas of karst topography produce poor crops in the higher areas because of lack of surface water and an excess of thin soils. However, in spring-fed valleys, crops are lush.

VII. Groundwater problems: As the population increases, problems with groundwater also increase. Some of these problems do not become evident until years after they first begin.

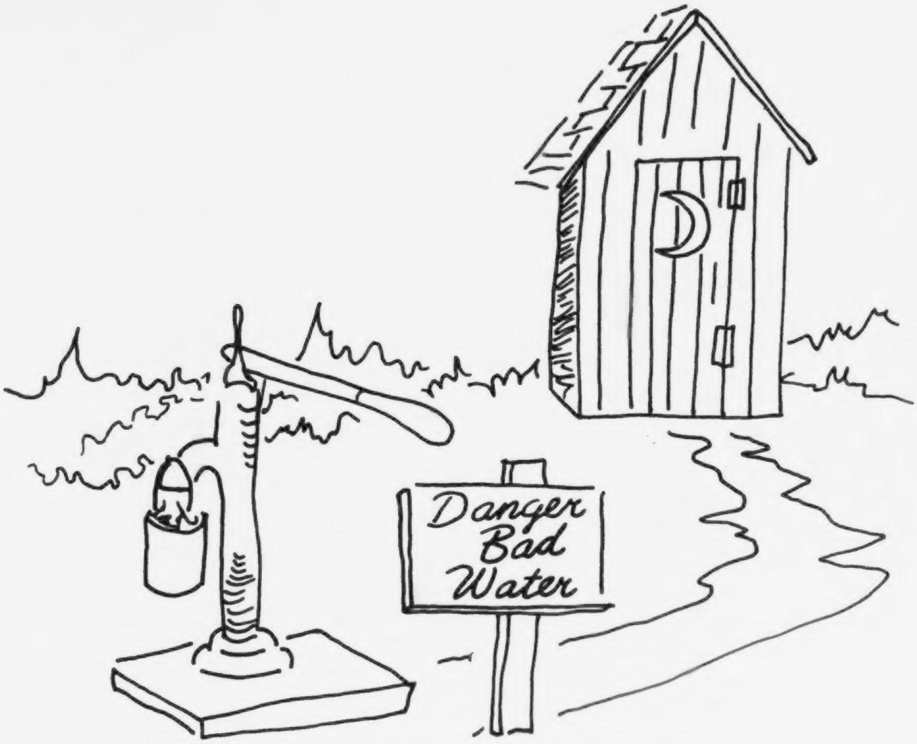
A. Pollution: The threat of groundwater pollution is substantial, and it can result from many causes.
    1. Septic tanks: Water from septic tanks seeps down to the water table.
    2. Holding ponds and lagoons: Unlined holding ponds for industrial wastes may leak down to the water table.
    3. Contaminated streams: Contamination from a polluted stream may migrate down through the ground.
    4. Land disposal of wastes: Rain washes through wastes, dissolves soluble products, and carries them into the ground and down to the water table. Sinkholes are frequently used to hold garbage. This provides an even more direct route to the water table.

B. Surface collapse: As solution continues, many regions of soluble rock may actually have sinkholes appear, causing damage to surface land as well as buildings and roads. Sinkholes in central Florida have a tendency to "eat" cars and houses from time to time.

C. Water table fluctuation: With seasonal rains and droughts, the water table will rise to possibly flood anything in its pathway or fall with resulting dry wells. As water is withdrawn from the zone of saturation, it may lower the water table below existing well levels, also resulting in dry wells.

D. Subsidence: A problem somewhat similar to surface collapse, but where the cause is due to withdrawal of groundwater from the zone of saturation to a point where the earth material subsides or sinks. Houston, Texas and other areas using vast amounts of groundwater are finding that parts of their cities are sinking up to 8 feet below the original surface level.

E. Salt water invasion: As groundwater is withdrawn along coastal areas, it is often replaced by salt water.



VIII. Summary: Unlike the behavior of surface water with which we are more familiar, groundwater behaves in an entirely different manner. Starting at the surface, it soaks down through the regolith and bedrock, at times seeking a lower level, yet at other times, creeping back up. Its behavior depends upon the type of material through which it is trying to seep. Once it reaches the water table, it is capable of destruction and creation. Given the presence of suitable material (primarily limestone), it can destroy large amounts of soluble rock, but during the process, it can create massive, awesome caves containing almost impossibly intricate depositional features. However, in the end, groundwater destroys the very features it created, carrying them in solution back to the sea to once more begin another circuit in their endless cycle.

SEE ACTIVITY 16.1

Extra Reading: If you are interested in further information, read the article, "Yes, Cave Monsters Really Exist," *St. Louis Post-Dispatch*, February 29, 1980, found on the next page.

Yes, Cave Monsters Really Exist

By Tim Renken
Of the Post-Dispatch Staff

No doubt you have heard horror stories about caves.

Perhaps when you were a child you heard tales about persons falling into "bottomless pits," persons starving when lost in a cave, persons being torn apart by cave monsters . . .

I'll bet, now that you're an adult, you no longer believe in cave monsters.

But they exist. One may even live near you.

I'll tell you some horror stories about cave monsters:

— A few years ago a cave monster was discovered in a cave shooting bats with a shotgun.

— Another time, a cave monster went into a Washington County cave renown for its colorful formations and went from end to end writing obscenities and names on the walls with a can of spray paint.

— Still another time, several cave monsters backed a truck up to the mouth of a Jefferson County cave and drove off with a truckload of formations.

Cave monsters do exist. They have two arms and two legs. Most amazing, they have two ears set on opposite sides of nature's only perfect vaccuum.

Cave monsters are the reason Missouri needs, and apparently is about to get, a law protecting caves. H.B. 1192 has passed the House of Representatives and is awaiting committee assignment in the Senate. The bill apparently has no opposition.

It says that a person "shall not willfully or knowingly break, crack, carve upon, write or otherwise mark upon, or in any manner destroy, mutilate, injure, deface, remove, displace, mar or harm the surfaces of any cave or any natural material therein, including stalactites, stalagmites, helictites, anothodites, gypsum flowers or needles, cave pearls, flowstone, draperies, rimstone, spathites, columns or similar crystalline mineral formations, including the host rock therof" without the written permission of the cave owner.

The bill bans also the harming or collecting of rare or endangered cave creatures and the deliberate pollution of a cave. And it relieves from liability owners of caves when persons exploring those caves are injured.

Passage of the bill would culminate a six-year effort by Missouri cave enthusiasts. Missouri, with more known caves (4,000 listed so far) than any other state and with some of the world's largest and most beautiful caves, is the only major cave state in the nation without some sort of cave protection law.

The lack of this law, said one of the state's foremost cave experts, St. Louisan Tom Cravens, has been catastrophic for many caves.

"You can't believe the vandalism in most of the more popular and accessible caves," he said. "Some have been stripped of their formations. Whole bat colonies have been obliterated. Many caves are so polluted they can no longer support most cave life."

Cravens tells of one cave near Sullivan, Mo., which was so beautiful that in 1956 the National Geographic magazine carried a photo story about it.

"Now you can't even find the places where those photos were taken because the formations have been destroyed," he said.

The problem of cave vandalism is growing, he said, because the sport of caving is growing in popularity.

"Several years ago, before the sport was popular, most of the people into it were serious and had an appreciation for what a cave represents," he said. "Now there are all kinds of people. Many of them don't realize what a priceless resource a cave is — or don't care."

Cravens pointed out that the formations in a cave are irreplaceable. Once destroyed, they are gone forever.

"They take hundreds and even thousands of years to form," he said, "and even in that kind of time a formation destroyed today won't be reformed just as it was."

Marking or spray-painting the walls also results in permanent, irreparable damage, Cravens said.

"If you try to scrape off or dissolve the paint, you destroy the deposits behind it," he said. "And you must remember that in a cave there are no natural processes to work on the marks. They stay there forever."

He pointed out also that the formations found in caves make poor items for home decoration.

"The formation which looked so beautiful in the cave is almost always just an ugly chunk of rock at home," he said. "The reason for that is moisture. When the formation is kept wet by the natural dripping, it is vibrant and colorful. When it dries out it gets ugly and usually ends up in the trashcan."

Cravens said that the most important effect of the law would be to grant legal recognition to the value of caves.

"A Law won't solve the vandalism problem because vandals don't care about laws," he said. "But this law will demonstrate the state's attitude about its caves."

4C Fri., February 29, 1980
ST. LOUIS POST-DISPATCH

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Chapter 16: Problems and Questions

1. List and describe three (3) sources of groundwater.
2. List and describe the factors affecting groundwater.
3. Diagram and describe the zone of aeration, zone of saturation, and water table.
4. Discuss two (2) reasons for the fluctuation of the water table.
5. Explain how the depth of the well sometimes determines its water-yielding capacity.
6. Diagram and describe an artesian system.
7. List and describe four (4) surface expressions of groundwater.
8. Describe the chemical process involved in cave development.
9. Discuss the development of limestone caves.
10. List and discuss the four (4) factors necessary for the development of karst topography.
11. Describe the stages of karst development.
12. Name some benefits from groundwater.
13. List and describe some environmental problems related to groundwater.

Unit V: External Processes

CHAPTER 17: Running Water

- I. Introduction
- II. Water Cycle Revisited
- III. Stream Development
  - A. Sources of Surface Water
    - 1. Runoff
      - a) Overland Flow
      - b) Channel Flow
    - 2. Groundwater
    - 3. Melting Glaciers
  - B. Base Level Concept
  - C. Stream Erosion
    - 1. Sheet Erosion
    - 2. Headward Erosion
    - 3. Abrasion or Corrasion
    - 4. Solution or Corrosion
    - 5. Hydraulic Action
  - D. Stream Transportation
    - 1. Stream Flow
      - a) Types of Flow
        - (1) Laminar Flow
        - (2) Turbulent Flow
      - b) Factors Affecting the Energy of the Flow
        - (1) Channel Size and Shape
        - (2) Gradient
        - (3) Cross-sectional Shape of the Channel
        - (4) Volume of Flowing Water
        - (5) Load
    - 2. Methods of Transportation
      - a) Suspension
      - b) Solution
      - c) Traction
  - E. Stream Deposition
    - 1. Factors Influencing Deposition
      - a) Loss of Transporting Power
      - b) Excessive Load
    - 2. Depositional Features
      - a) Sediment Bars
      - b) Floodplain
        - (1) Natural Levee
        - (2) Backswamp
        - (3) Meander Deposit
      - c) Alluvial Fan
      - d) Delta

IV. Drainage Systems
  A. Development of Drainage Basins
    1. Network of Tributaries
    2. Main Stream Channel
    3. Network of Distributaries
  B. Drainage Patterns
    1. Deranged
    2. Dendritic
    3. Trellis
    4. Rectangular
    5. Radial
    6. Parallel
    7. Annular

V. Valleys and Rock Structure
  A. Stream Valley Development
    1. Valley Deepening
    2. Valley Widening
    3. Valley Lengthening
  B. Types of Stream Valleys
    1. Consequent Stream Valley
    2. Subsequent Stream Valley
    3. Antecedent Stream Valley
    4. Superposed or Superimposed Stream Valley
  C. Evolution and Valley Development
    1. Stages of Erosion
      a) Initial Development
      b) Intermediate Development
      c) Final Development
    2. Factors Affecting Evolution and Valley Development
      a) Climate
      b) Structure of the Rock
      c) Type of Rock
  D. Interruptions in the Erosion Cycle
    1. Causes for Complications
      a) Diastrophism
      b) Change in Base Level
      c) Glaciation
      d) Change in Climate
    2. Results of Interruption
      a) Rejuvenation
        (1) Entrenched Meanders
        (2) Terraces
      b) Misfit Streams

VI. Streams and Humanity
  A. Benefits
    1. Drinking Water
    2. Energy
    3. Transportation
    4. Recreation
    5. Agriculture
    6. Industry

B. Problems
  1. Flooding
  2. Pollution
  3. Sand Bars
  4. Erosion

VII. Summary

Floodplain Seminar Today

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Related Activities

Vocabulary

Identify Stream-related features on topographic maps and aerial photos.

Fill in charts on running water information.

Problems and questions

Running Water Geo Facts

Streams stray from the straight and narrow by taking the path of least resistance. So do people.

Five percent of the United States is floodplain; 2.5 percent is coastal area.

Sediment, the mud and solids washed from the land surface, is one of the largest pollutants of our waterways.

Humans are responsible for more than doubling the world rate of erosion.

Stream channels, on the average, contain only enough water to maintain their flow for about two weeks before needing groundwater to supplement their source of water.

United States' streams carry an average of 45 trillion 6 hundred billion liters (1.2 trillion gallons) of water every day to the oceans.

The longest stream in the world is the Nile.

The largest stream in water capacity is the Amazon.

The Mississippi drains one-third of the United States.

When the Mississippi floods, its load of sediment jumps to four million metric tons (4.5 million U.S. tons) a day. That is equal to a 15 centimeter (6 in) layer of topsoil from forty-six 100-acre farms.

Water is the only common substance that occurs naturally in all three states (solid, liquid, and gas).

Water constitutes about 65 of the total weight of the human body.

Chapter 17: Word List

Abrasion
Alluvial Fan
Alluvium
Annular drainage
Antecedent Stream
Backswamp
Base Level
Bed Load
Braided stream
Channel
Consequent stream
Corrasion
Corrosion
Cutoff
Delta
Dendritic drainage
Deranged drainage
Diastrophism
Distributary
Downcutting
Drainage Basin
Drainage divide
Drainage system
Entrenched meander
Floodplain
Geomorphic cycle
Gradient
Headward erosion
Hydraulic action
Intermittent stream
Laminar flow
Load
Meander
Meander belt
Meander scar
Misfit stream
Monadnock
Natural levee
Overland flow
Oxbow lake
Parallel drainage
Pediment
Peneplain
Perennial stream
Plunge pool
Pothole
Radial drainage
Rectangular drainage

Word List-Continued

Rejuvenation
Runoff
Sand bar
Sediment
Sheet erosion
Shut-in
Slipoff slope
Solution
Stream
Stream erosion
Stream flow
Stream piracy
Stream transportation
Stream valley
Subsequent stream
Superimposed stream
Superposed stream
Suspension
Terrace
Traction
Tributary
Trellis drainage
Turbulent flow
Water gap
Watershed
Wind gap
Yazoo stream

Straight Terms

Antecedent
Consequent
Dispersal
Recede
Simplistic
Subsequent
Superimpose
Trough
Velocity
Volume

UNIT V: EXTERNAL PROCESSES

Chapter 17: Running Water

I. Introduction: When standing on the surface of the earth, it is difficult to determine the precise landscape. When viewed from afar in an aircraft, though, it is very obvious that valleys dominate our landscape. These valleys are carved by running water, specifically streams. A stream is any water that moves across the surface of the land in a channel or trough. Terms have been assigned by the general public to distinguish between streams of different relative sizes--river, stream, brook, or creek. However, geologically, we will limit our usage to the term stream, regardless of its size. A channel is the bed of the stream upon which the stream water flows. It is through the erosion of the channel that valleys are formed. This chapter will include stream development and its effects on the landscape and on people.

II. Water cycle revisited: In review, because of its importance, recall the water cycle. With the sun providing the energy, water from the surface of the oceans is evaporated into the atmosphere as water vapor, a gas. As the water vapor in the air is lifted and cooled, it condenses to fall as precipitation. Much of the precipitation evaporates before reaching the earth's surface or immediately after so doing. Another large portion is used by vegetation and is transpired back into the atmosphere. The remaining part of the water that falls as precipitation moves over and through the earth. Streams contribute to the water cycle by ultimately delivering water back to the oceans.

III. Stream development: Surface water experiences a rather impressive manner of organizing itself into a potentially powerful end product. Once a stream has formed, it may possess the energy to reduce the land to a nearly flat surface close to sea level. As with most situations, though, it is best to start at the beginning. Once upon a time...

A. Sources of surface water: It all begins with a drop of precipitation. Upon reaching the earth, precipitation can travel several different routes before reaching a stream.

1. Runoff: This consists of any water that simply flows off the land. The erosive ability of runoff is controlled by the slope of the ground, the amount of vegetation, the amount of precipitation, and the permeability of rocks on or near the surface.

a) Overland flow: Overland flow is the movement of water in a broad film and/or network of small, interconnected rills (tiny streams). It occurs when the rate of precipitation exceeds the rate the water soaks into the ground. Overland flow is not very obvious and occurs only for short distances before entering a stream.

b) Channel flow: This is surface water that flows between well-defined banks. This type of runoff is very easy to see because the gullies appear as scars on the land.

2. Groundwater: Rain soaks into the ground to become groundwater. Much of this water eventually enters streams by seepage and springs.

3. Melting glaciers: Some precipitation temporarily becomes locked up in glaciers. When they melt, the water is released to find its way to streams.

B. Base level concept: An understanding of base level will aid you in your study of stream development. As a stream flows downstream, it possesses the ability to erode. If the stream enters a standing body of water, it loses this ability to erode. The surface level of a standing body of water is called the base level; it is at this level that erosion by a stream is limited. (See Figure 17.1) When a stream enters a lake, that body of water is a local, or temporary, base level. The ultimate base level for streams is sea level. An imaginary line is projected inland from the base level, as shown in Figure 17.1, and a stream will continue to erode until it reaches the level of the imaginary line, or base level. Base level remains the same unless there is a change in lake or sea level or if the land subsides or is uplifted.

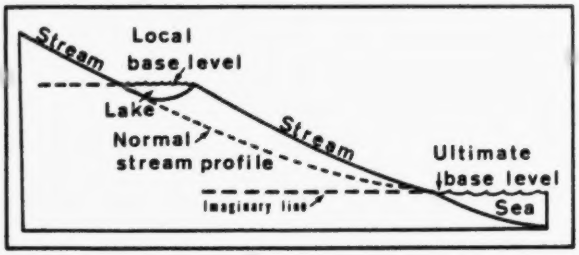


Figure 17.1. Illustrates a local or temporary base level created by a lake and the ultimate base level at sea level. The normal stream profile is the path of the stream had the lake not been present.

C. Stream erosion: This is the progressive removal of material from the stream channel. Running water, aided by mass-wasting, is the most important factor in the sculpturing of the landscape, even in arid climates. It is estimated that running water lowers the land elevation, at a worldwide rate, about 2.5 centimeters (1 in) per 1,000 years. Furthermore, it has been estimated that the present worldwide rate of erosion has doubled since the introduction of the axe and plow. Why? Stream erosion is accomplished by several mechanical processes.

1. Sheet erosion: This is the erosion that is performed by overland flow. A continuous cover of vegetation strongly reduces the erosion. However, bare slopes, closely grazed pastures, or freshly tilled fields are highly susceptible to sheet erosion although no obvious valleys are created. A great deal of the load carried by a stream is from sheet erosion. It is rarely noticeable because the removal is fairly uniform over the surface and consists of only a thin layer.

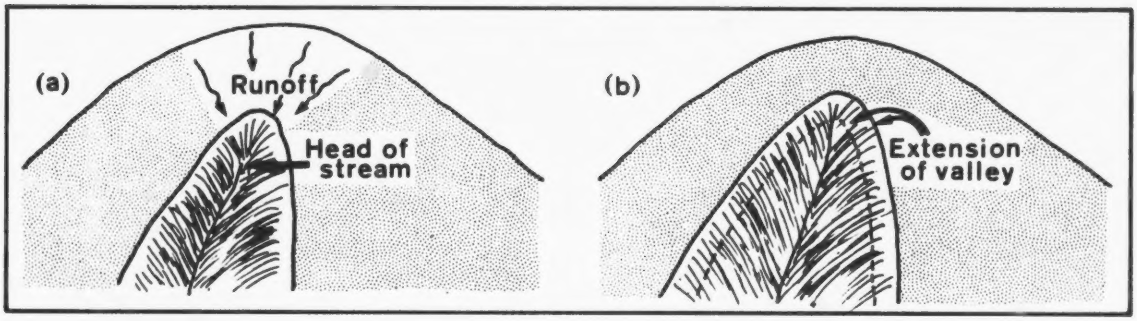
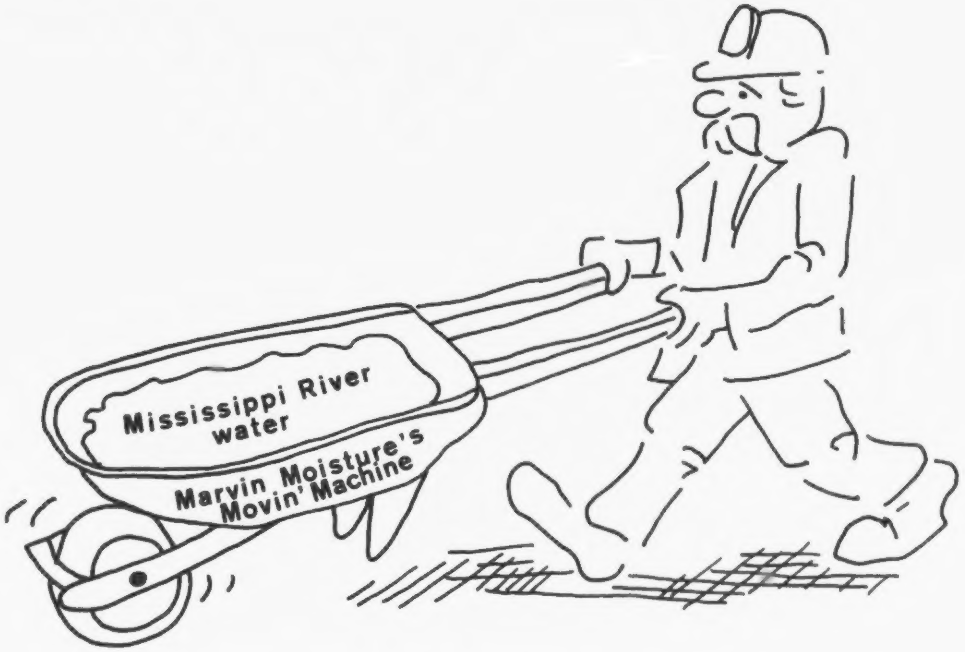


Figure 17.2. (a) illustrates the head of a stream. (b) illustrates headward erosion. Notice how the stream is progressively extending the size of the valley.

2. Headward erosion: The head of a stream is its upper end, where it begins. Headward erosion is the erosion, and therefore the extension, of the head of a stream by the incoming runoff. (See Figure 17.2) It is speeded up by weathering and slumping.
3. Abrasion or corrasion: This is the mechanical wearing away of a rock. It is caused by friction from rubbing, scraping, and grinding. Running water carries sediment (the load) such as sand and gravel. While the sediment is swept along, the stream uses it as a tool to rub, scrape, bump, and crush the bedrock exposed in the channel. (When a stream is abrading its bed, it is known as downcutting.) In the process of abrasion, the components of the tool (the sediment) in turn are abraded, smoothed, and reduced in size. Sometimes abrasion performs a drilling action, concentrating on one location, creating a depression or hollow in the stream floor, called a pothole. Many times large potholes form at the base of nearly vertical waterfalls, and they are called plunge pools. (See Figure 17.29)
4. Solution or corrosion: This is the removal of material by chemical dissolving action. It is a very effective way of lowering the land surface. Of course, its ability to dissolve depends upon the kind of rock it encounters, with limestone and dolomite being fairly soluble. Most of the material carried in solution by the stream probably comes from groundwater seepage, but solution also can occur directly in the stream channel.

5. Hydraulic action: This is the sweeping away of loose material such as soil, clay, sand, and gravel by moving water. You use hydraulic action to clean soil off a sidewalk with a hose. Occasionally, moving water exerts pressure by entering into cracks in the rock and quarrying out slabs or blocks from the channel floor or sides.

D. Stream transportation: This is the ability, or mechanical means, of running water to transport or carry sediment. Running water is a major agent of erosion because of its ability to transport enormous quantities of sediment that were previously eroded. There are several factors influencing the quantity of sediment to be transported.



1. Stream flow: This is the ability of water to move or advance downstream. Stream flow exists because of the pull of gravity.
    a) Types of Flow: There are two paths in which the water in a stream flows.
        (1) Laminar flow: In this type of flow, the water moves in parallel paths as though it is made up of fine layers that are free to slip over one another. There is no turbulence. (See Figure 17.3) It is limited to an area along the bottom and walls of the stream channel and is promoted by either high or low velocity in smooth channels.

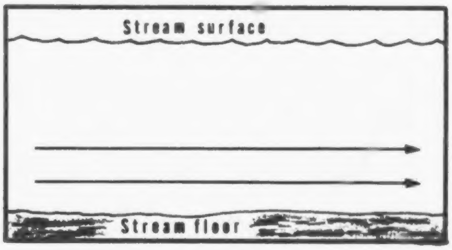


Figure 17.3. A side view of laminar flow. The water moves in parallel lines.

(2) Turbulent flow: This is a kind of flow in which the water movement is irregular with a corkscrew motion. It is brought about by obstructions which tend to deflect the water movement. It is promoted by a high stream velocity and rough channels. (See Figure 17.4)

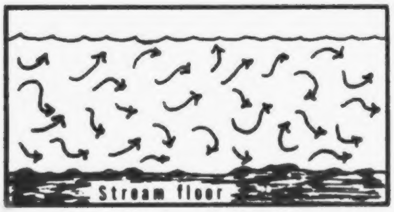


Figure 17.4. A side view of turbulent flow. The water moves in a corkscrew manner.

b) Factors affecting the energy of the flow: These factors listed below can all be interrelated.

(1) Channel size and shape: The greater the surface area of the channel (that is, the larger the area including the sides and bottom), the more the flow of water will be contained. Deep narrow channels and wide shallow channels meet this condition. (See Figure 17.5)

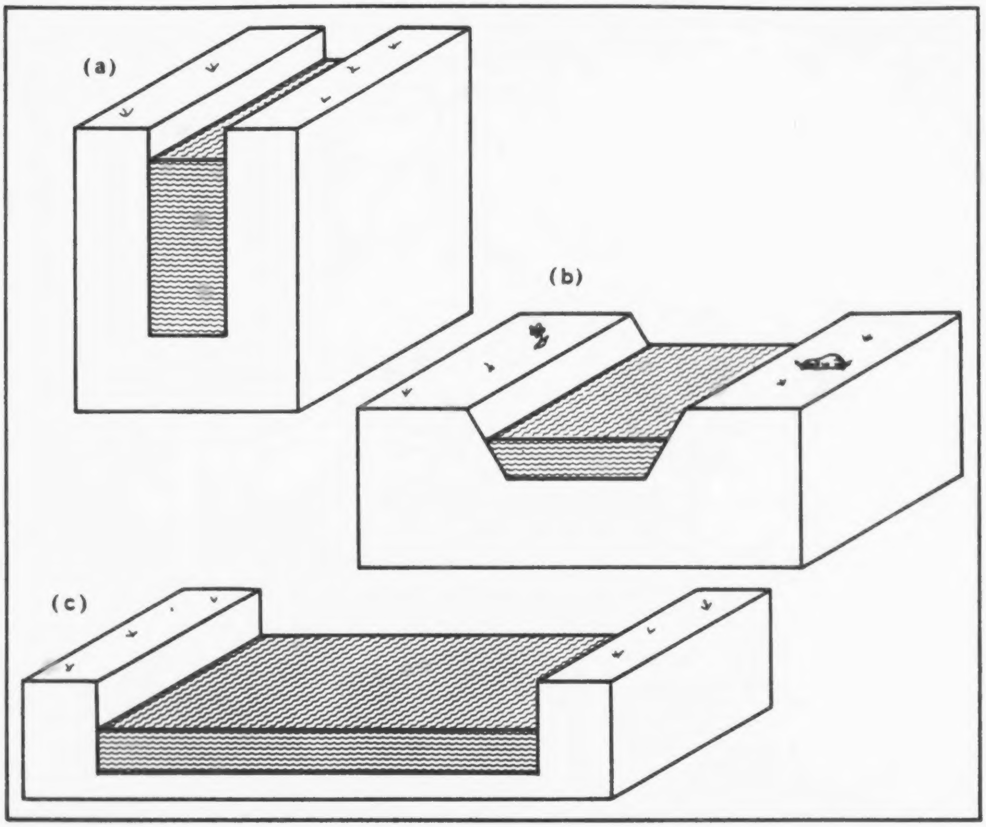


Figure 17.5. Illustrates the relationship between the stream channel shape versus the velocity. (a) and (c) have a greater area of contact with the sides and bottom of the channel and are therefore slowed down by friction.

        (2) Gradient: Gradient is the slope of the stream measured at intervals from the source to the end of the stream, stated in meters per kilometer. Of course, the steeper the gradient, the faster the flow.
        (3) Cross-sectional shape of the channel: The cross-section is measured from side to side of the channel along the bottom. The larger this area, the greater the friction. A rough slope will create more turbulence, and it will slow down the flow.
        (4) Volume of flowing water: The greater the amount of water, the faster the flow downstream.
        (5) Load: This is the material that is carried by a stream. It will be further discussed later. The load also affects the stream flow. The larger the load, the slower the velocity.
    2. Methods of transportation: Sediment (the load) can be transported in three ways.
        a) Suspension: This is the carrying of clay and silt particles by upward currents in the stream. Normally, in still water, these particles would settle to the bottom. Turbulence prevents this settling and holds the particles indefinitely. As a stream progresses downstream, the amount of sediment in suspension increases. It is called the suspended load and accounts for two-thirds of the material being transported.
        b) Solution: As was mentioned before, this is the dissolved material being carried by the stream. It is called the dissolved load.
        c) Traction: This is the mode of transportation that rolls or slides material along the bottom of the stream bed. Traction is one of the major tools of stream erosion. The main factor determining the largest boulder that a stream will be capable of moving is the velocity of the water. All of the matter that moves along the bottom of the stream, from large angular fragment to small rounded fragments, is called the bed load.

E. Stream deposition: If any change such as a change in base level or slope occurs to alter the conditions that allow a stream to transport, it will drop its load, or deposit it. Stream deposits are called alluvium.
    1. Factors influencing deposition: There are two fundamental causes for stream deposition.
        a) Loss of transporting power: The inability of a stream to transport a load can result from a reduction in the stream's velocity caused by a decrease in the slope, by an increase in the spread of stream waters, by obstructions such as dams, or by a decrease in the volume of water. A volume decrease can be caused by increased vegetation, climate change, or stream diversion by human beings.
        b) Excessive load: The stream may have too large of a load because of great quantities of glacial sediment, because of increased erosion from reduced vegetation cover, or because of excessive loads from easily eroded areas near the head of the stream.
    2. Depositional features: There are a variety of features associated with stream deposition.
        a) Sediment bar: Commonly known as sand bars, these features can be composed of sediment from clay size to boulders, depending upon what size sediment a given stream can carry. Sediment bars form where streams slow down. Locations include along the stream banks, the inside of a curve of the stream (called a meander), and at obstructions like islands or log jams.
        b) Floodplain: A floodplain is the flat, low-lying area adjacent to a stream. They are created as the stream cuts laterally and widens its valley. When floods occur, the excess water (and sediment) flows out onto this surface. As the water recedes, sediment is deposited on this flat surface. The fact that the sediment is usually fine in size and rich in organic matter make floodplains excellent agricultural regions. (Except

during the flood!) In addition to the floodplain itself, several features are formed within the floodplain.

(1) Natural levee: A natural levee is a low ridge, usually no more than several feet in height that parallels the stream banks. They form where the floodwaters first spill out of the channel and drop a sediment load. (See Figure 17.6)

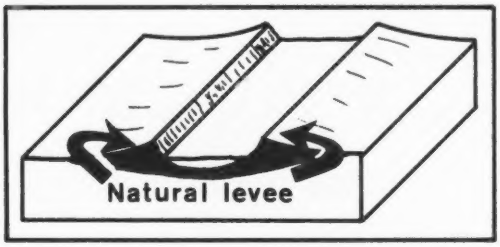


Figure 17.6. Natural levees are wedge-shaped deposits found directly along stream banks.

(2) Backswamp: When water floods areas behind a natural levee, all the water cannot return to the main channel as the flood recedes. Consequently, a swamp may be created. In the Mississippi Valley, they are extensive south of Vicksburg, Mississippi, to Donaldsonville, Louisiana. (See Figure 17.7)

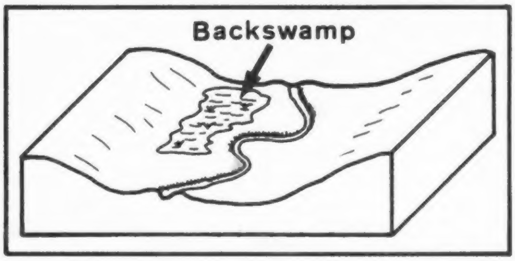


Figure 17.7. Floodwaters become trapped behind natural levees to create backswamps.

(3) Meander deposits: A meander is a bend in the stream. It is a location of both erosion and deposition. In a cross-sectional view of a meander, the outside wall is steep and undercut by erosion. The opposite side has a more gentle slope and is called the slipoff slope. This is the site of deposition, a location of sand bars. (See Figure 17.8)

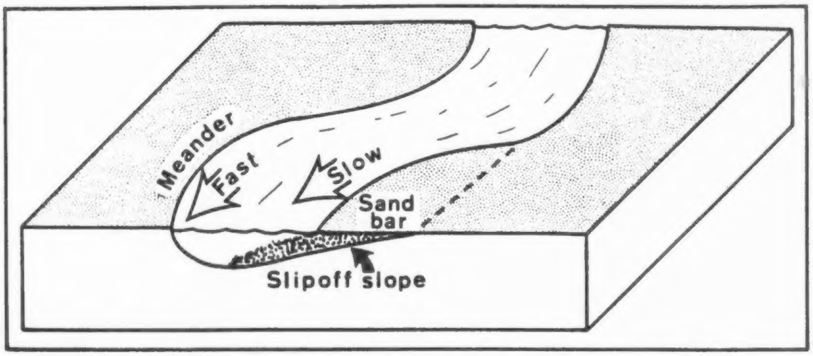


Figure 17.8. A cross-section of a meander. The outside of the bend is the site of erosion because of the greater water velocity. The slipoff slope is the site of deposition because of a slower velocity.

Meanders can eventually form hairpin curves, and the stream may break across the narrow neck of land at the base of the loop to create a new and relatively short channel called a cutoff. (See Figure 17.9)

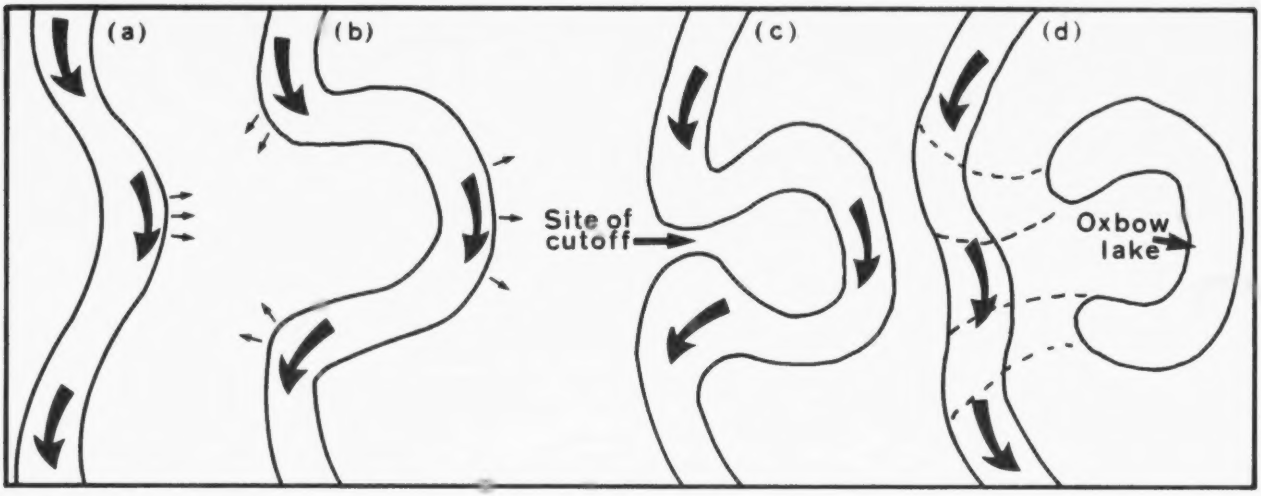


Figure 17.9. Illustrates the progressive erosion forming a cutoff and oxbow lake. (a), (b), and (c) show the bending of a meander. (d) is the new stream course with the abandoned channel comprising an oxbow lake.

c) Alluvial fan: Alluvial fans are most common in areas with little vegetation and relatively large sediment. The formation occurs when heavy rains wash large amounts of the sediment into steep mountain streams, when the stream reaches the flat valley floor (base level) the sediment is deposited. (See Figure 17.10) A series of adjacent fans form a bajada.

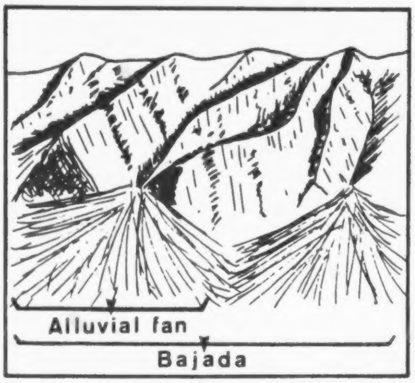


Figure 17.10. An illustration of an alluvial fan and bajada.

d) Delta: A delta is an alluvial deposit in water that is similar to an alluvial fan. It is triangular in shape and is found at the mouth of a stream. (The mouth of a stream is at the stream's end.) A delta forms as a result of a quick decline of energy when one stream enters another stream or a standing body of water, such as a lake or ocean. For instance, where the Missouri River enters the Mississippi River, a delta forms. Not all streams form deltas. Some carry such a small load as to make a delta impossible. Others are prevented because the streams' mouths are exposed to strong currents. Thriving under positive conditions is the Mississippi River delta, formed as the Mississippi River enters the Gulf of Mexico. It is an excellent example of delta construction and has an area of 30,960 square kilometers (12,000 mi^2). It has extended approximately 200 kilometers (125 mi) since the beginning of the Pleistocene epoch of the Cenozoic era.

IV. Drainage systems: Now, with the mechanics of streams firmly embedded in your mind, let us stand back and survey the entire network of connecting channels. Water organizes itself into drainage systems consisting of areas of land that are somewhat leaf-shaped and within which all water in that area is drained. Each system is bounded by a drainage divided (the rim of a drainage system). Each of these specific areas is called a drainage basin or watershed.

A. Development of drainage basins: A drainage basin begins to develop when water from runoff is collected, concentrated, and funneled into a definite path or gully. The water in a network of these channels drains into larger streams. (A tributary is a smaller stream that flows into a larger one.) It is through this continuous funneling that a drainage basin develops. A typical drainage basin can be divided into three portions.

1. Network of tributaries: A network of tributaries is a gathering system in which water is collected from all the minor rills, gullies, and channels to be funneled into the main trunk of the stream. (See Figure 17.11) This portion of a drainage basin is the primary source of water and sediment, and it is here that the most active erosion takes place.

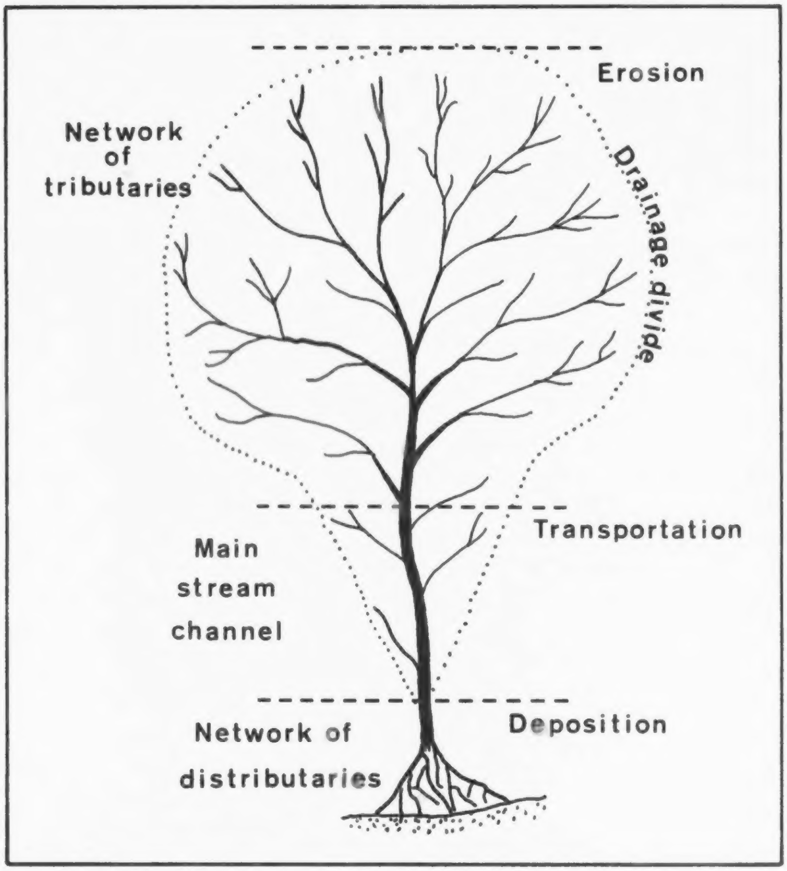


Figure 17.11. Illustration of an idealized drainage basin. The water is traveling from the top of the diagram to the bottom. The left side of the diagram names the different parts of a drainage basin. The right side describes the primary job performed in each part.

2. Main stream channel: This portion of a drainage basin consists of the main stream and the larger tributaries. Its major job is to transport water and sediment out of the drainage area. It might be added that some additional water and sediment may be added to the stream in this area, and some deposition may also occur during flooding.
3. Network of distributaries: Distributaries are the branches at the mouth of the stream into which a stream divides when it reaches its delta. In this part of a stream system, water dispersal dominates, and most of the stream's sediment is deposited.

B. Drainage patterns: Weathering, mass-wasting, sheet erosion, and stream activities shape the land into a system of channels that can have several different patterns. The patterns are controlled by the kind of bedrock upon which they are developed and the geologic history of the area in which they occur. Some of these patterns are simple channel patterns. Others, because of the amount of erosion that has taken place, have developed into valley patterns. There are several types.

1. Deranged: This is the term given to areas where there is no definite drainage present. Swamps and lakes occupy shallow depressions. (See Figure 17.12) Deranged drainage is common in newly glaciated areas such as Minnesota and Wisconsin, where former drainage was eliminated and new drainage has not had time to develop.

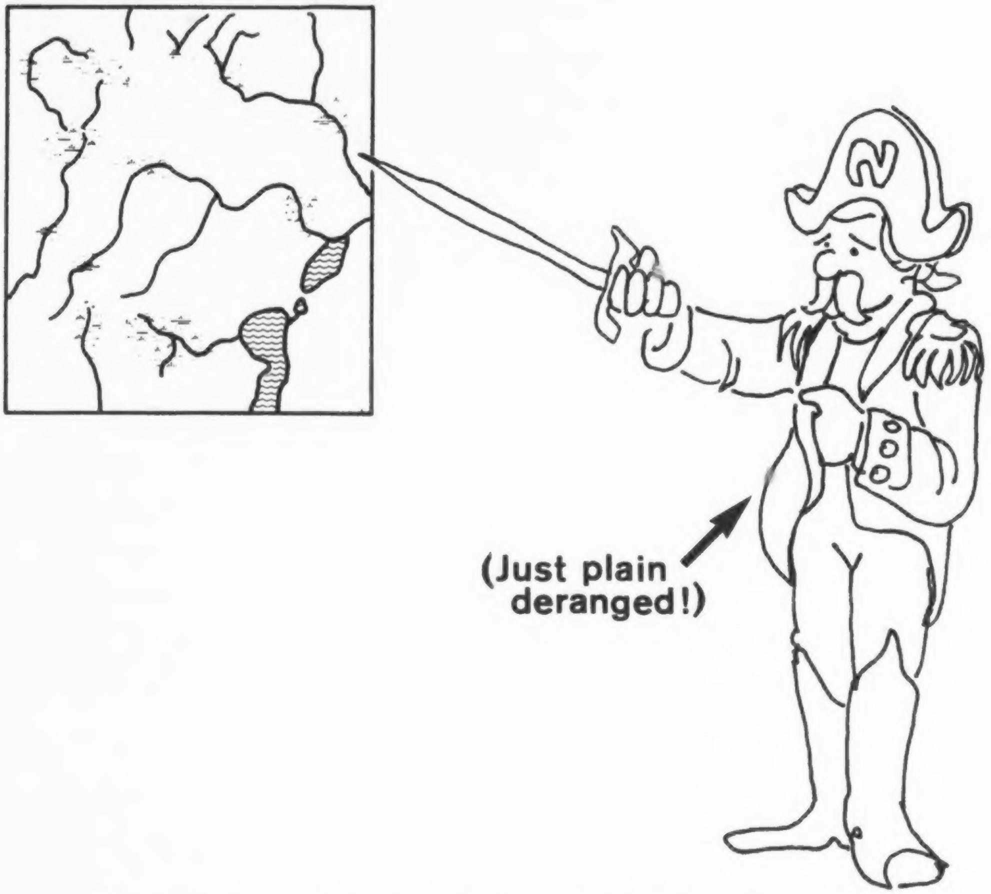

(Just plain deranged!)

Figure 17.12. An aerial view of a deranged drainage pattern.

2. Dendritic: Arranged like the limbs of a tree, this pattern is characterized by the irregular branching of the tributaries. (See Figure 17.13) It develops in areas where the underlying rock is of uniform resistance and primarily on horizontal sedimentary and massive igneous rocks. This pattern is most common in the midwestern United States in the Central Lowlands region.

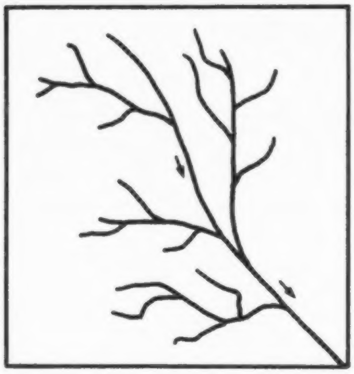


Figure 17.13. An aerial view of a dendritic drainage pattern. The arrows indicate the direction of stream flow.

3. Trellis: With this drainage, the tributaries meet the main stream at right angles, while the main streams are nearly parallel, aligning themselves with the strike of the rock formations. (See Figure 17.14) Tributaries are controlled by the structure of the rock and are especially common in the folded mountains such as the Appalachians.

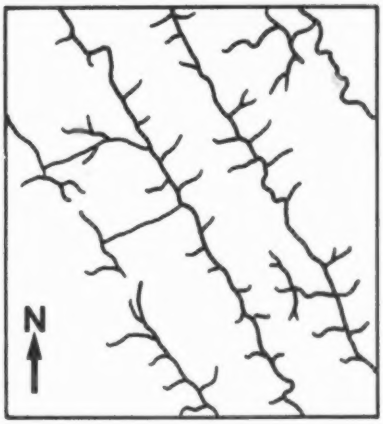


Figure 17.14. An aerial view of a trellis drainage pattern. The strike of the rock is northwest-southeast. Between the streams are ridges.

4. Rectangular: In rectangular drainage, the stream and its tributaries make right-angled bends because they follow fault lines and joints. The right-angled displacement is referred to as offset drainage. (See Figure 17.15) This offset stream pattern is well-developed in the Adirondack Mountains.

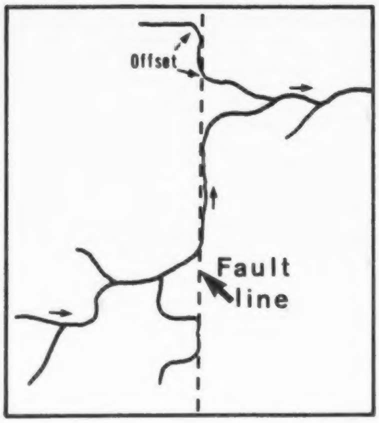


Figure 17.15. An aerial view of a rectangular drainage pattern.

5. Radial: Streams radiate from a central point in radial drainage. (See Figure 17.16) This is common on volcanic cones such as those in the northwest United States, and on domes.

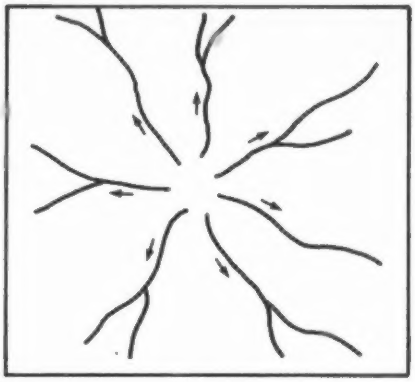


Figure 17.16. An aerial view of a radial drainage pattern.

6. Parallel: In this type of drainage, streams over a large area tend to run parallel to each other and are found where there are pronounced slopes or structural controls which lead to regular spacing. (See Figure 17.17) Such can be found on the Atlantic Coastal Plain.

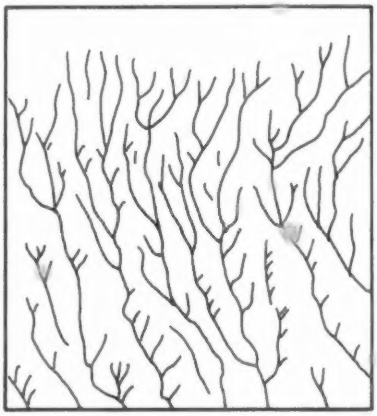


Figure 17.17. An aerial view of a parallel drainage pattern.

7. Annular: This is a ringlike drainage associated with maturely dissected domes or basins. (See Figure 17.18) Here, the drainage is controlled by the alternating beds of strong, circular rock ridges (hogbacks, as you recall from Chapter 12) and weak rock. The Black Hills of South Dakota with its uplifted domal structure, offers a good example of annular drainage.

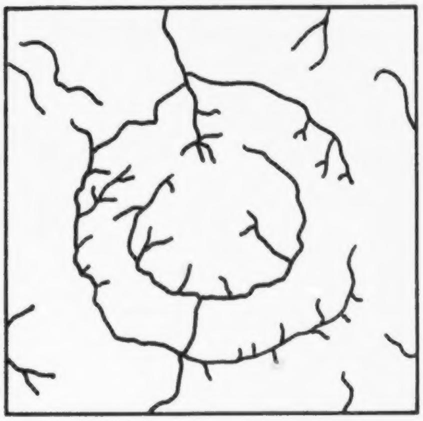


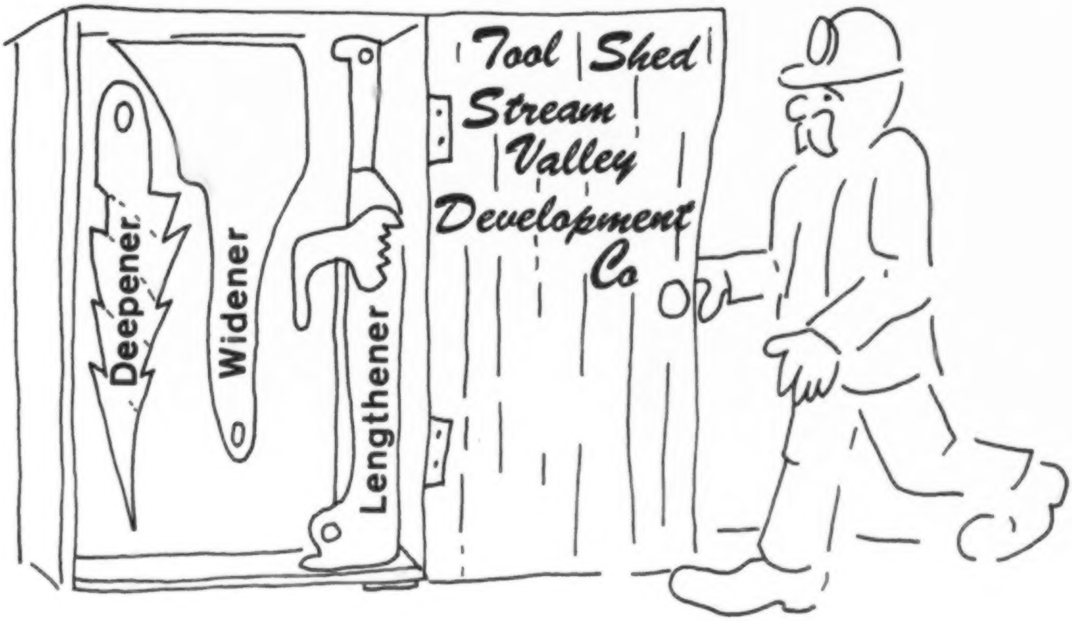
Figure 17.18. An aerial view of an annular drainage pattern. The circle-shaped streams flow on weak rock beds with hogbacks in between.

V. Valleys and rock structure: Valleys are so common that textbooks rarely define them. Commonly known as gully, draw, ravine, gulch, hollow, run, arroyo, gorge, canyon, vale, glen, or dale, just for our record, a stream valley is a stretch of lower land lying between higher land, and it results from erosion by running water. (Remember that valleys began as channels that have since enlarged through the process of erosion to become valleys.) Valleys are occupied by either perennial streams (those streams that flow all of the time) or intermittent streams (those streams that have water in them periodically). They should not be mistaken for famous locations with valley names, such as Death Valley, which were created by diastrophism.

A. Stream valley development: A stream valley forms and develops through various erosion processes. Obviously, it can increase in depth, width, and length. Consider each process.

1. Valley deepening: In following the laws of nature, streams are forever chewing away at valley floors to reach base level. They do so through hydraulic action, abrasion and pothole drilling, occasional solution with cooperative rock, and perhaps weathering if the stream is intermittent.
2. Valley widening: Numerous processes combine to create a widening of a stream valley. The most important of these processes is called meandering or lateral cutting. This occurs when a stream begins to use part of its energy to cut sideways, not just down. As the water moves faster on the outside of a bend (meander), the stream continues to widen its valley. The stream, however, does not gain all of the channel width, since while cutting on the outside, sediment is deposited on the inside of the bend where the water slows down. (See Figure 17.8) Meanders can eventually form hairpin curves, and the stream may break across the narrow neck of land at the base of the loop to create a new and relatively short channel called a cutoff. (See Figure 17.9) While there is still water present in the abandoned meander, the feature is known as an oxbow lake. When filled with sediment and vegetation they are called meander scars. Hydraulic and abrasive action undercut the base of valley sides which then favor slumping. Sheet erosion simply extends the width farther inland. When valleys have little bedrock, weathering simply loosens the material which is then mass-wasted. When bedrock is present, weathering is slower but still works to loosen it. Incoming tributaries make valleys more

vulnerable to widening because the valley wall is attacked from two directions. Such is the case when the Missouri River and the Mississippi River meet.


Tool Shed
Stream Valley Development Co
Deepener
Widener
Lengthener

3. Valley lengthening: A valley can be made longer by extending it at the stream's head or mouth. Headward erosion eats at the upslope area of the stream. It is sometimes responsible for stream piracy--the capture of one stream's water by the headward erosion of another's. (See Figure 17.19) If the land is uplifted or if sea or lake level becomes lower, a valley will extend across the newly exposed land. As deltas build up, streams will become longer. A good example is the Mississippi River delta which has been discussed previously.

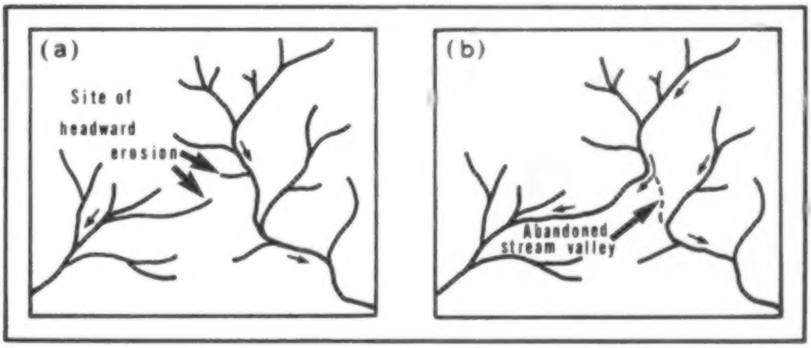

(a)
Site of headward erosion
(b)
Abandoned stream valley

Figure 17.19. (a) illustrates the site of future stream piracy. The large arrows show the sites of the headward erosion involved in the stream piracy. (b) illustrates stream piracy with the stream on the left diverting the flow of the upper portion of the stream on the right.

B. Types of stream valleys: There are several different types of valleys, and the differences are based upon their patterns and other characteristics.

1. Consequent stream valley: If a stream's path is controlled solely by the slope of the surface of the ground, it is known as a consequent stream valley. (See Figure 17.20) Its path is a consequence of the slope. Straight stream patterns, dendritic, and radial stream drainage patterns form consequent stream valleys. They are common on the Coastal Plain and on the sides of young mountains such as the Sierra Nevada Range, in California, and the Wasatch Range, in Utah.

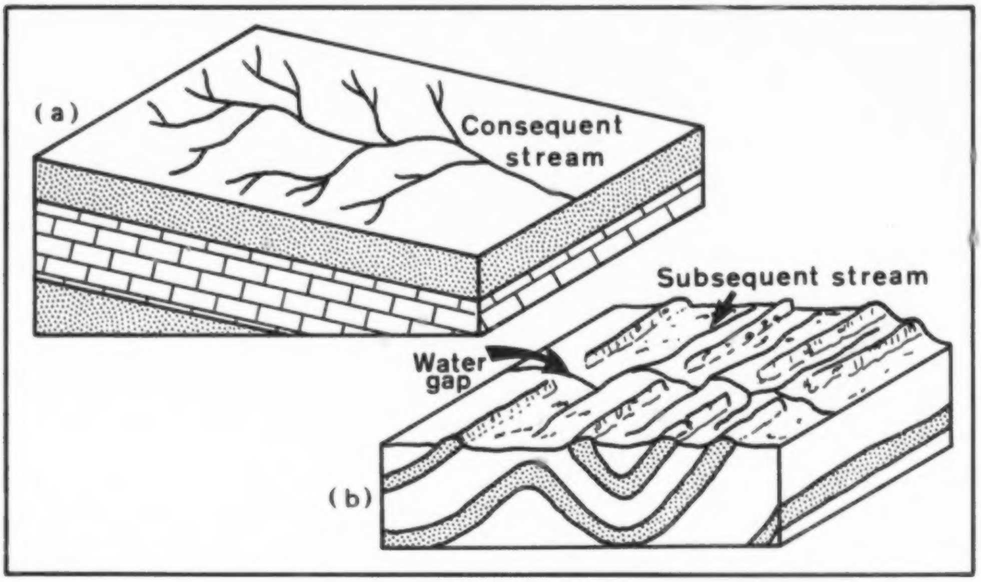


Figure 17.20. (a) is a consequent stream--a consequence of the slope. (b) is a subsequent stream, forming along belts of weak rock.

2. Subsequent stream valley: If the stream's course has become adjusted to the underlying rock and follows a path as a result of the underlying structure rather than the original slope of the land, it is called a subsequent stream valley. It is subsequent to the slope. It tends to follow soft rock belts. Rectangular, annular, and trellis patterns form in this manner. (See Figure 17.20)
3. Antecedent stream valley: When a stream maintains its course regardless of later earth movements such as folding or faulting, it forms an antecedent stream valley. (See Figure 17.21) These valleys are usually confined to regions of recent mountain building such as the Columbia Gorge of the Columbia River through the Cascade Mountains, between Washington and Oregon.
4. Superposed or superimposed stream valley: When a stream originates on one type of a strata and cuts its channel onto buried bedrock having a different kind of structure and rock, it forms a superposed stream valley. (See Figure 17.22) Most of the gorges in the Rocky Mountains are the result of superposition. A subsequent, antecedent, or superposed stream valley can form a water gap--a pass in a ridge through which water flows. These are also known as shut-ins. If water has ceased to flow through the pass, it is called a wind gap.

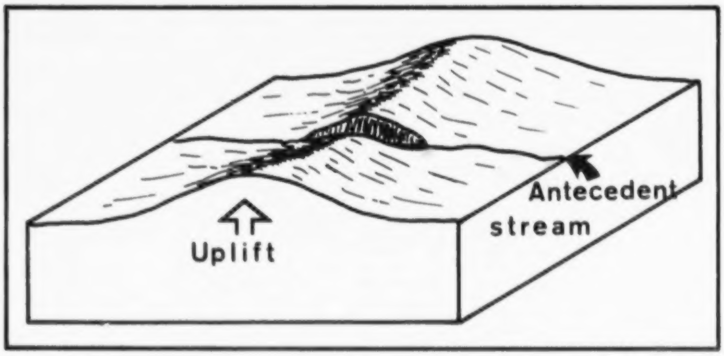


Figure 17.21. Illustrates an antecedent stream. These form before the structure develops and continue to downcut during diastrophism.

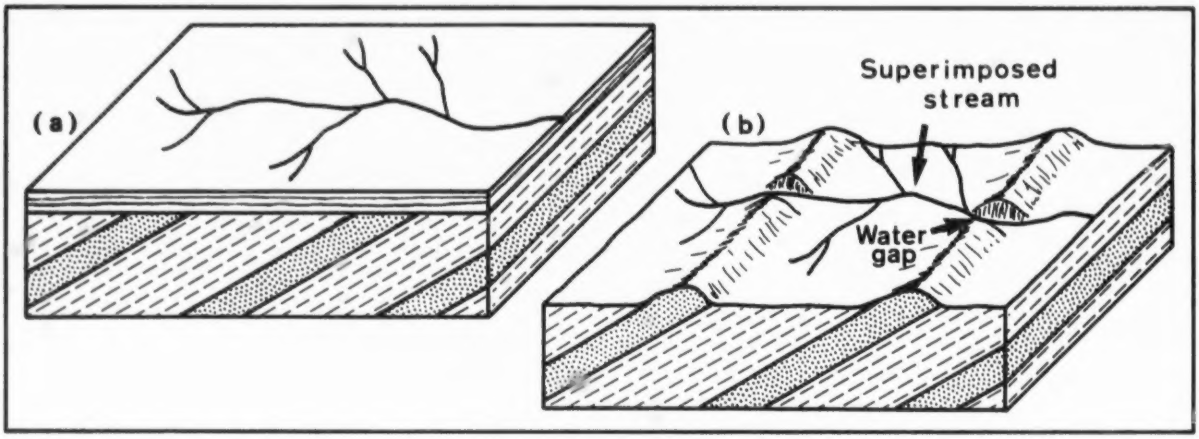


Figure 17.22. (a) illustrates a stream with an established channel. (b) illustrates the same channel after erosion. Note that the once buried strata did not influence the original course.

C. Evolution and valley development: In theory, an area that has been uplifted goes through a series of changes because of the effects of running water until that area is eroded to base level. This sequence of changes is known, classically, as the cycle of erosion or the geomorphic cycle. (Geomorphic refers to the landforms of the earth.) The steps in the sequence of changes are called stages, of which there are three. The cycle of erosion is under criticism because it occurs under too idealistic and simplistic conditions. It is given attention, however, because no one has provided an improved classification of the evolution of landforms.

1. Stages of erosion: Listed below are several features and characteristics of the three different stages of the erosion cycle in a humid climate. Some of these characteristics refer to the development stage of the stream valley, whereas others refer to the development stage of the region. Keep in mind that there is no sharp line between the different stages of the erosion cycle. The entire process is continuous. It is also possible that some streams in an area might not fit exactly into one of the stages. That some streams in an area may not be in the same development stage of the erosion cycle as the region is

conceivable also. For example, a region may be classed as being in the intermediate development stage, but it may have within it individual valleys that appear to be in their initial development or some that may even be approaching final development. In addition, one stream may be in different stages at various locations.

a) Initial development: In order for valley development to begin, the area must be uplifted above base level, causing water to move down, and eventually to develop a valley. The higher above base level, the faster the water moves to increase downcutting. Stream valleys are V-shaped and often deep. Streams are actively extending themselves by headward erosion. There are few tributary streams. Under certain specific conditions, it is possible that the upland areas between streams (interfluves) are poorly drained, are flat, and are the sites of lakes and swamps. Waterfalls and rapids may exist in the stream channels because downcutting takes place so fast that more resistant rock strata are not removed as fast as poorly consolidated materials. Young streams carry both coarse and fine materials, but little material is deposited. Near the end of this stage, stream channels are smoother, and the streams begin to meander. As a result of these activities, there are undercut banks, slipoff slopes, valley widening, and floodplain development. (See Figure 17.23)

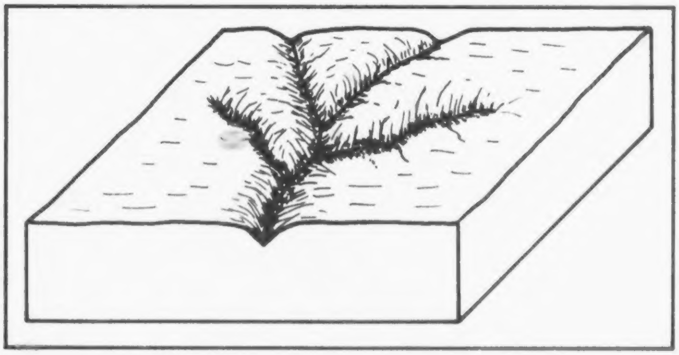


Figure 17.23. Illustrates the initial development of a stream valley and surrounding terrain.

b) Intermediate development: As the stream valley becomes closer to base level, downcutting is decreased; lateral cutting is dominant. The stream gradient is smooth, and most falls and rapids have been removed. There is a maximum number of tributaries. The main stream is meandering, and the width of the meander belt (the farthest distance from the far edge of one meander to the far edge of the next meander) equals the width of the floodplain which has begun to develop. (See Figure 17.24)

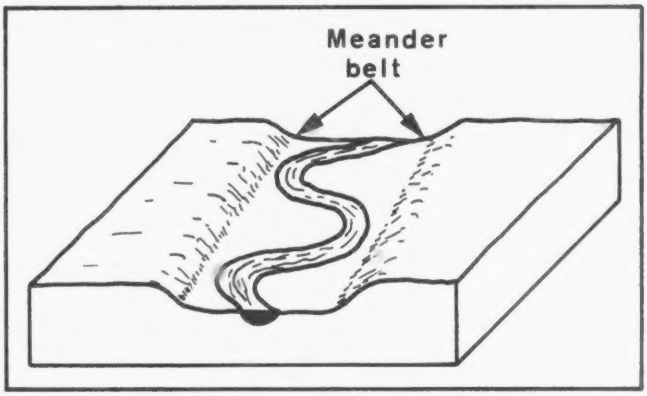


Figure 17.24. An illustration of a meander belt.

The valleys are broad and well-defined. Relief is at a maximum in the headwaters region. Drainage divides are high and narrow. (See Figure 17.25) Few lakes exist, and drainage in the region is at a maximum. Near the end of this stage, several features might occur: meander cutoffs, oxbow lakes, and meander scars.

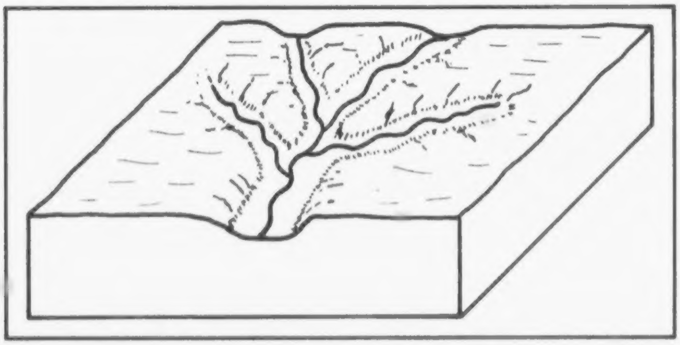


Figure 17.25. Illustrates the intermediate development of a stream and the surrounding terrain.

c) Final development: At this point, nearly all land is reduced to base level; however, this might be only a temporary base level. Meanders are very numerous. The width of the floodplain is several times that of the meander belt. Lakes, swamps, and marshes may be present on the floodplains. Streams are no longer downcutting and are heavily loaded with sediment. Deposition often occurs in the stream channel resulting in braided streams. Natural levees may exist along the stream margins. Relief in the area is low, and remnants of divides are low and narrow. (See Figure 17.26) Present are yazoo streams (streams that enter the floodplain but cannot flow directly into the main stream because of the blockage by a natural levee; instead, the secondary stream flows parallel to the main stream until the main stream can be entered). The ultimate development in the erosion cycle is a peneplain, a surface of very low relief, quite near base level. A few isolated erosional remnants known as monadnocks may be present upon the peneplain. The whole idea of a peneplain is debatable because it is believed by some geologists that there is no definite evidence that any exist. In addition, land masses do not remain at the same elevation for a long enough time period to permit an area to be reduced to base level.

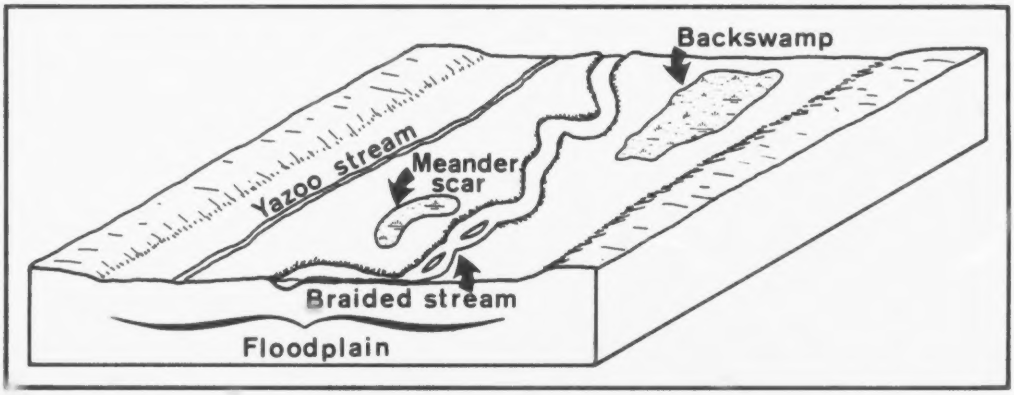


Figure 17.26. Illustrates the final development of a stream valley and the surrounding terrain.

2. Factors affecting evolution and valley development: There are several conditions that will affect the erosion cycle.
    a) Climate: The erosion cycle of an arid or semiarid climate is much the same as in a humid climate. However, the landforms differ. In an arid climate, the topography is much more angular because sandstones and limestones form steep cliffs while shales form broad slopes. In humid climates, weathering rounds most slopes. Slope retreat is much more obvious in arid climates. Many of the tributary streams are always dry except during and after heavy rains. An arid area is characterized by an erosional surface called a pediment; a pediment is a rock-floored plain directly next to a mountain and results from the erosion of the mountain. It is usually covered with a layer of alluvium. (See Figure 17.27)
    b) Type of rock: As just noted, different rocks have levels of resistance and different weathering characteristics. Resistant and non-resistant rock layers are a major cause of waterfalls. (See Figure 17.28)

D. Interruptions in the erosion cycle: The erosion cycle can and, in most likelihood, will be interrupted at some point by one or more of several interferences.
1. Causes for interruption: The following are the most important reasons for an interruption in the erosion cycle. As with most geological processes, they are often related.
    a) Diastrophism: As you recall, this is movement of the earth's crust such as broad regional uplift, subsidence, folding, or faulting. If the upstream portion of the stream is uplifted in relation to the downstream portion, the stream has renewed energy for valley deepening.

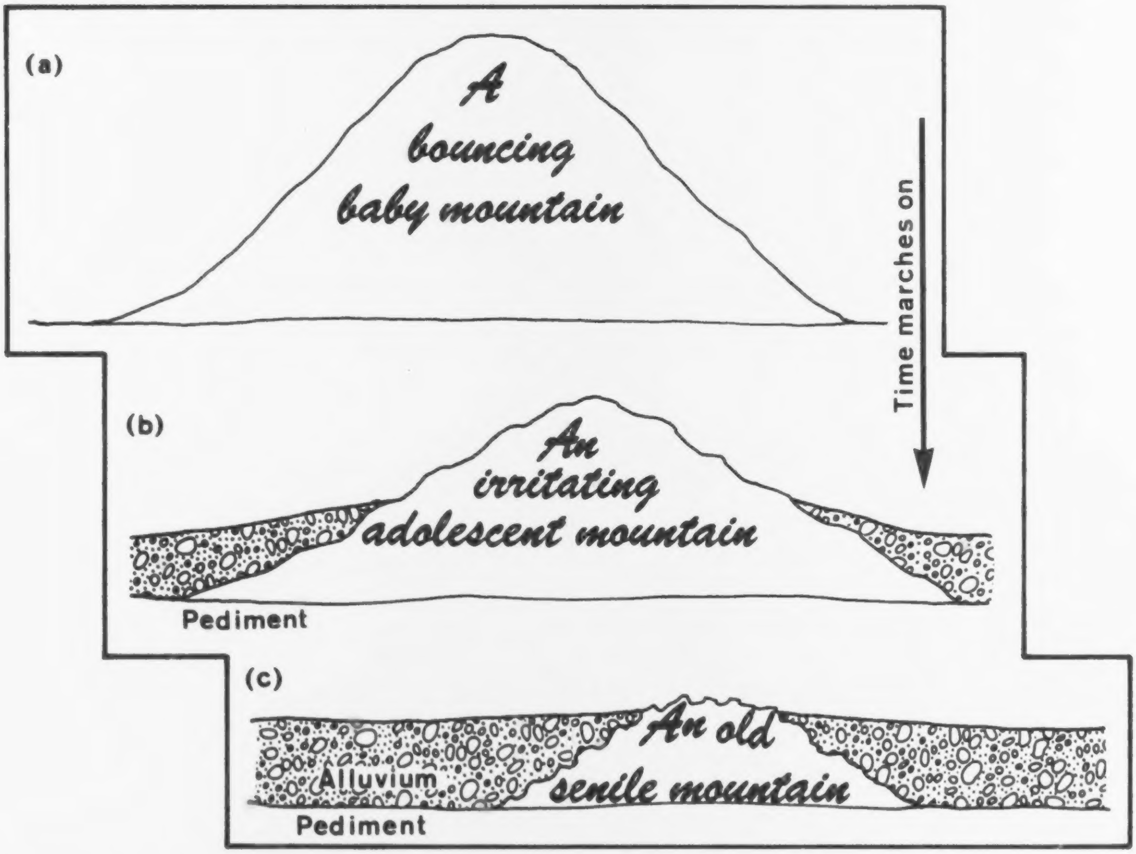

(a)
A bouncing baby mountain
Time marches on
(b)
An irritating adolescent mountain
Pediment
(c)
An old senile mountain
Alluvium
Pediment

Figure 17.27. (a) illustrates a new mountain. (b) illustrates the same mountain after it has had a few years to erode. (c) illustrates the same mountain many years and much erosion later. The pediment is that portion of the original mountain that has been eroded away and is now nearly level.

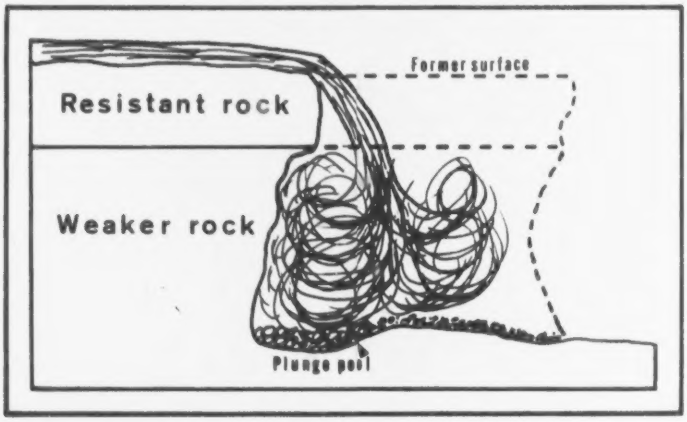

Former surface
Resistant rock
Weaker rock
Plunge pool

Figure 17.28. Illustrates the effect of rock structure and rock type on water falls. This is a simplified diagram of Niagara Falls.

b) Change in base level: The rise or fall in sea level can change the base level of the stream. A rise will interrupt the erosion cycle by slowing down the erosion of a stream because there is less rock surface to destroy, and the base level is raised. The opposite occurs when the base level is lowered.

c) Glaciation: Glaciation can have several results. Glaciers cover the land and erase the drainage system below them by dumping debris. They also deposit debris along their margins when they melt so that remaining streams are forced to carry huge loads of sediment. As a result, instead of eroding, the streams deposit the debris in their valleys. It is believed that the lower Mississippi River contains 61 meters (200 ft) of sediment accumulated from glacial sediment.

d) Change of climate: Climatic changes can cause the cycle to speed up by providing more water or to slow down with less water. An example of slowing down the cycle is found with glaciers, because they temporarily hold much water from the water cycle in the form of ice.

2. Results of interruption: The result of changes in the erosion cycle is often found in features found within the stream valley.

   a) Rejuvenation: Rejuvenation is any change which gives a stream renewed energy to engage more actively in valley deepening. It can result from diastrophism, a change in base level, or a change in climate.

      (1) Entrenched meanders: Evidence of rejuvenation can be seen in entrenched meanders--meanders that are preserved within steep walls. Entrenched meanders form when the base level changes, and a meandering stream then has the energy to downcut its present meandering course. A classic example of this is the San Juan River in Utah.

      (2) Terraces: Rejuvenation is also responsible for terraces. These are remnants of former floodplains after a stream downcuts to a lower level. (See Figure 17.29) Reasons for further downcutting include the uplift of land, the increase of stream energy, or the lowering of the base level.

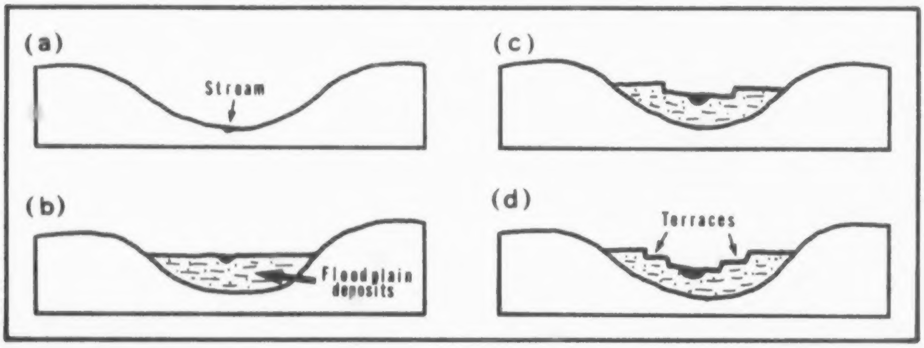


Figure 17.29. Terraces form when a stream downcuts into a floodplain because of an increase in energy. The terraces are remnants of a former floodplain.

b) Misfit streams: These are streams that are not in proportion to the size of valleys that they occupy. In most cases, the valley is considerably larger than the stream that occupies it. They result either from stream piracy or past glaciation. Many valleys acted as drainage ways for melting glaciers and thus carried large volumes of water. After the glacial ice melted and flowed to sea, the valleys were then the location of smaller streams.

VI. Streams and humanity: Streams generally provide many more benefits than problems. They have had a tremendous influence on humanity and our civilization.

A. Benefits: (The list could easily be longer.)

1. Drinking water: Many communities near large streams use the stream water as their major source of drinking water. In addition, many communities dam the streams to create reservoirs (lakes) for a water supply.
2. Energy: Today, running water is the source of hydroelectric power in many mountainous areas of the United States and the world.
3. Transportation: Streams provide economical transportation of resources (except when the streams are frozen).
4. Recreation: Hundreds of thousands of dollars are spent for water recreation equipment. (Realize that water skiing is quite difficult on grass!)
5. Agriculture: Flooding leaves rich deposits of alluvium for farming, although dams have lessened this benefit through flood control. In addition, irrigation has made many arid regions agriculturally productive.
6. Industry: Factories frequently locate near running water because of the advantages, such as easy transportation of goods and convenient dumping grounds for wastes. (See Problems below.) Fishing is also an industry dependent upon "ole man River."

B. Problems: People do have problems with running water. It might be noteworthy to add that some of these problems may not have existed if humanity had used more wisdom in choosing locations to inhabit and in the use of water.

1. Flooding: Increasing population in stream valleys causes problems with flood protection. The problem has partially been solved through the construction of dams and levees and through proper zoning.
2. Pollution: Industrial and human waste create pollution problems because of inadequate treatment. Only through the enforcement of strict Environmental Protection Agency standards can this problem be controlled.
3. Sand bars: Sand bars choose their own locations, and those locations sometimes coincide with human-made creations such as loading docks. The sand must be dredged out, sometimes, to provide underwater depth for barges to approach the docks.
4. Erosion: Erosion can always be a problem near a stream; therefore, wise selection of building sites (or whatever) would be a smart precaution.

VII. Summary: The expression "Strength in Numbers" is quite apt when considering the effects of running water. A mass accumulation of harmless-looking raindrops has the power to carve valleys and thereby sculpture the land. The systematic, efficient work of running water begins by collecting water in a specific land area and, through various means, eroding this area. The running water then progresses to an area in which transportation dominates. When the base level is reached by the running water, water and sediment are dispersed, and the sediment deposited. Running water is active in two cycles--the water cycle and the rock cycle. Streams return the water back to the sea. They return broken-down rock in the form of sediment back to the ocean floor to begin the formation of more rock and numerous topics for geology students.

SEE ACTIVITY 17.1

SEE ACTIVITY 17.2

Chapter 17: Problems and Questions

1. Compare the three (3) sources of stream water.
2. In detail, describe the formation of a stream.
3. Discuss the five (5) factors affecting the energy of the flow.
4. Compare the three (3) methods of stream transportation.
5. Discuss the effects of base level on stream erosion.
6. Describe two (2) reasons why a stream may deposit its load.
7. Discuss the factors that may affect the erosion cycle.
8. Name and describe the four (4) causes of erosion cycle interruption.
9. Describe the benefits of running water. Include two (2) that are not mentioned in the text.
10. Discuss the problems of running water. Include two (2) that are not mentioned in the text.

Unit V: External Processes

CHAPTER 18: Glaciation

I. Introduction

II. Origin of Glaciers
  A. Mechanics of Glacial Development
    1. Zone of Accumulation
    2. Glacial Movement
    3. Zone of Ablation
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    2. Abrading
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    2. Arete
    3. Col
    4. Horn
    5. Glaciated Valley
    6. Paternoster Lakes
    7. Roche Moutonnee

IV. Glacial Transportation

V. Glacial Deposition
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    2. Water Deposits
    3. Wind Deposits
  B. Features Deposited
    1. Features Composed of Till
      a) Moraine
        (1) End (Terminal) Moraine
        (2) Ground Moraine
        (3) Recessional Moraine
        (4) Lateral Moraine
        (5) Medial Moraine
      b) Drumlin
    2. Features Composed of Glaciofluvial Deposits
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      d) Esker
      e) Kame
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VI. Types of Glaciers
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- A. History of Glacial Activity
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- B. Evidence for Worldwide Glaciation
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- C. Causes of Glaciation
- D. Geographic Extent of the Pleistocene Ice Sheets
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- E. Aftermath of the Pleistocene Ice
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  - 2. Effects on Life
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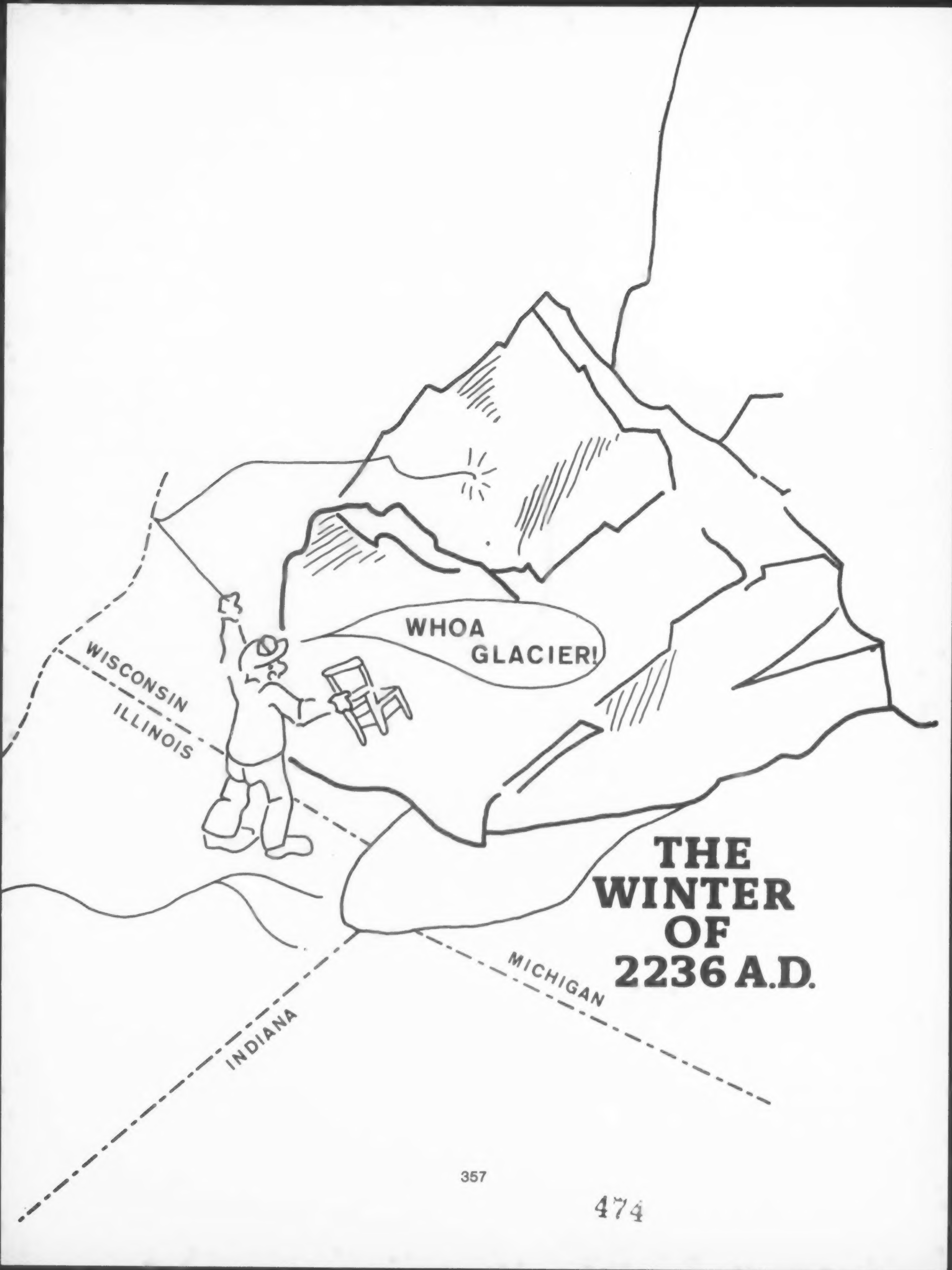
    - c) *Homo sapiens* in North America
- F. The End, Middle, or Beginning

VIII. Glaciers and Humanity
- A. Benefits
- B. Problems
- C. Future

IX. Summary


WHOA GLACIER!
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA

THE WINTER OF 2236 A.D.

Related Activities

Vocabulary

Identify glacial features on topographic maps and aerial photos.

Fill in charts on glacial features.

Answers (you provide the questions.)

Glacier Geo Facts

Glaciers are noisy critters, punctuated by sharp cracks, booms, and groans (noises much the same as geology students make while caving).

If present glaciers were to melt, the sea level would rise as much as 90 meters (300 ft), flooding present coastal areas throughout the world.

Today, glaciers cover about 10 percent of the world's land area.

Without counting Alaska, the United States has about 1,100 glaciers, most of which are valley glaciers. Washington State is the site of 800 of those glaciers.

During the Pleistocene, the oceans were crowded with icebergs carrying glacial sediment. When they melted, the sediment settled to the bottom of the ocean. This sediment included an unusual assortment ranging in size from huge boulders to clay.

If the Greenland icecap melted, it would yield enough water to maintain the Mississippi River for somewhat more than 4,700 years.

Three-fourths of all the fresh water in the world (60 years of precipitation over the whole globe) is in the form of glacial ice.

In some states, such as Washington and Alaska, glaciers exert an influential, even a dominating, effect on the supply of dry-season water, and naturally regulate streamflow to even out the seasonal and year-to-year variations in precipitation.

Chapter 18: Word List

Terminal Terms

Arete
Bergschrund
Cirque
Col
Continental glacier
Crevasse
Drift
Drumlin
End moraine
Erratic
Esker
Firn
Fjord
Frost wedging
Glaciated valley
Glaciation
Glacier
Glaciofluvial deposit
Ground moraine
Hanging valley
Headwall
Horn
Ice lobe
Kame
Kettle
Lateral moraine
Loess
Medial moraine
Meltwater
Moraine
Neve
Outwash
Outwash plain
Paternoster lake
Piedmont glacier
Plucking
Quarrying
Roche moutonnee
Rock flour
Snowfield
Snowline
Striations
Tarn
Terminal moraine
Till
Till plain
U-shaped valley
Valley glacier
Valley train
Varve
Zone of ablation
Zone of accumulation

Straight Terms

Abate
Ablate
Amphitheater
Brittle
Erratic
Hexagonal
Sinuous

UNIT V: EXTERNAL PROCESSES

Chapter 18: Glaciation

I. Introduction: In the two previous chapters, erosion, both by groundwater and running water, was discussed. Erosion can also be accomplished by glaciers. A glacier is a body of ice that is made up of recrystallized snow that is able to flow on a land surface. Glaciation is the change of land by the movement of glaciers over it. Of all the water found on earth, only 2.8 percent is not found in the oceans. Of the 2.8 percent, 2.06 percent of this is frozen. Antarctica contains 90 percent of the world's ice; that means that most of the world's fresh water is located there. One-fifth of the scenery of the earth has been created by the work of glaciers. Most striking is the work of valley glaciers, those glaciers that form on mountains and later flow down into valleys. In contrast are continental glaciers which are broad and cover a large surface area of land. From a scientific point of view, one can regard glaciers as that part of the water cycle in which water is on land in a solid state. It is held on land longer than its liquid form which attempts to return quickly to the sea. This chapter will present to you the chilling topic--glaciation.

II. Origin of glaciers: A glacier will form when the amount of snow that accumulates is more than the amount lost by melting and evaporation. When the glacier becomes thick enough, it will begin to flow under its own weight. To arrive at this stage, there are several transitions during which snow is changed into glacial ice.

  A. Mechanics of glacial development: The accumulated snow over a wide area is called a snowfield. The lower limit of the snowfield is called the snowline. (See Figure 18.3) It is within the snowfield that the snow converts to glacial ice. Glacial ice must reach a minimum thickness believed to be between 30.5 and 46 meters (100 and 150 ft) thick before becoming a glacier. That is why some snowfields never develop into glaciers.

    1. Zone of accumulation: This is the area of the snowfield above the snowline where there is snow all year. At this location, there is a net gain of ice each year because more snow accumulates than is lost. It is here that snow is transformed into ice. This recrystallization is much the same process as that involved in the creation of metamorphic rock from sediment. (See Figure 18.1) Fresh new snowflakes are hexagonal in shape, and there may be as much as 90 percent void space within an area of freshly fallen snow. As the snow accumulates, the pressure on the snow increases, resulting in increased temperature. This melts the tips of the snowflake, and the melted snow migrates toward the center of the flake and refreezes forming pellets of ice called firn or neve. (See Figure 18.2) Further accumulation of snow adds further pressure on the firn. Daily temperature changes result in meltwater (melted snow or glacial ice) which seeps through the pore spaces to refreeze, eventually forming solid glacial ice. When the ice is approximately 49 meters (160 ft) thick, the force of gravity causes it to start to move or flow, provided there is some degree of slope.

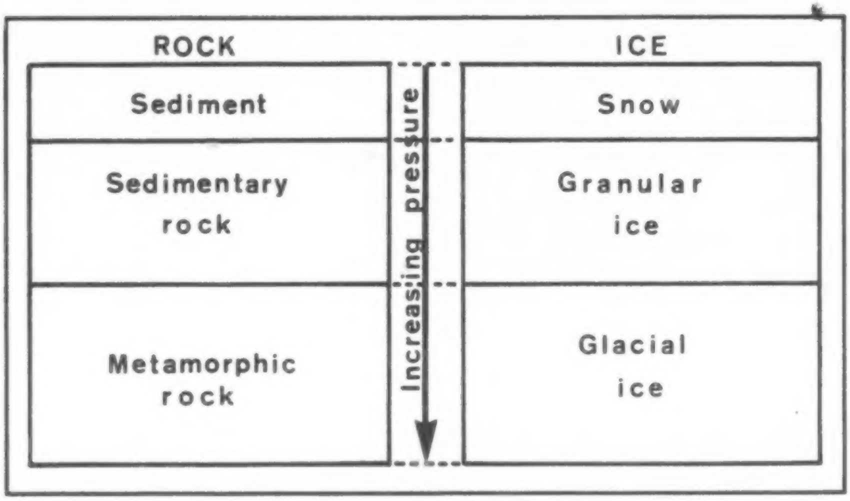

ROCK
ICE
Sediment
Sedimentary rock
Metamorphic rock
Increasing pressure
Snow
Granular ice
Glacial ice

Figure 18.1. Compares the change of sediment into metamorphic rock to the change of snow into glacial ice.

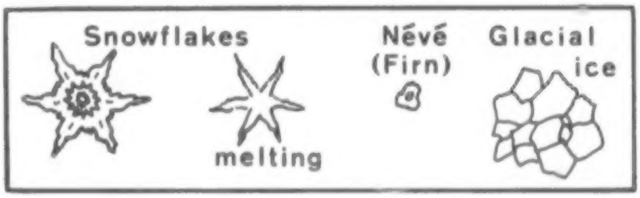

Snowflakes
melting
Névé (Firn)
Glacial ice

Figure 18.2. Illustrates the transformation of a snowflake into glacial ice.

snow
névé
ice
cooler
mini glacier

2. Glacial movement: Regardless of the growth rate of the glacier, the internal motion within the ice is always toward the margin. The deeper levels of the ice flow in a plastic manner. Under the influence of melting and pressure, blocks of ice can also slip over each other like a stack of cards. The lower portion carries the upper brittle portion. Because the upper portion is brittle, deep gaping cracks called crevasses form when the ice is subjected to tension such as that created by the glacier moving over an obstruction. (See Figure 18.3) The speed can vary from zero to 30 or more meters (100 ft) per day. Ice advancement is determined by the steepness of the slope, the thickness of the ice, the roughness of the surface under the ice, and the temperature of the ice.
3. Zone of ablation: Ablation includes the different processes by which a glacier wastes away. These processes include melting and sublimation (the evaporation of a solid directly to a gas). The zone of ablation is at the lower end of the glacier. If more snow accumulates than is lost, the glacier will advance. If more snow ablates (melts or evaporates) than accumulates, the glacier will retreat. If accumulation and ablation are equal, the glacier will remain stationary, or inactive. Regardless of the movement of the glacier front, remember that the internal portion of the glacier remains in motion until the glacier has ablated enough to be inactive or dead.

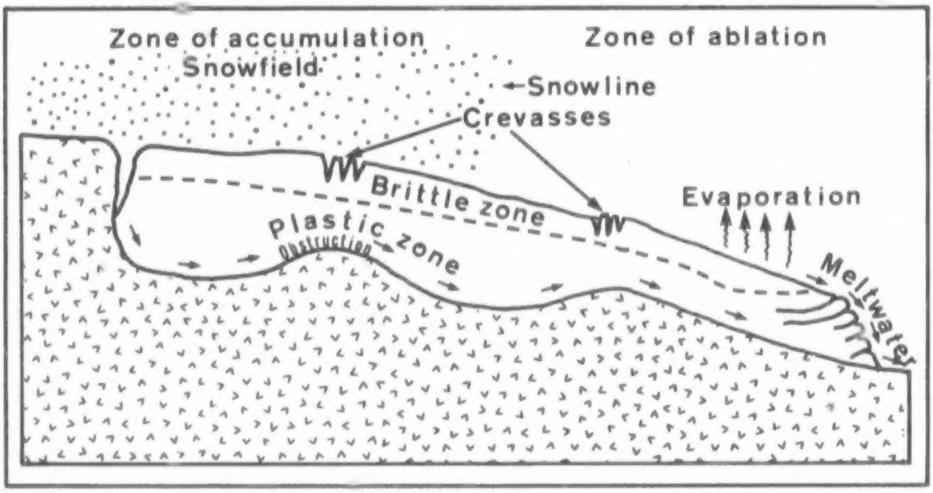


Figure 18.3. A cross-section of a glacier showing the plastic and brittle zones. Note that the crevasses may form when the glacier flows over a rise.

B. Conditions necessary for glacial formation: The precise cause of glacial formation is not known. There are several theories that suggest causes, though. These include changes in the amount of energy that the earth receives from the sun, continental movement, changes in the location of the earth's rotational (not magnetic) poles, or changes in ocean circulation. The correct theory must explain the change in climate making glacial formation possible. While each theory has limitations, at least the conditions for glacial formation are known. An increase in precipitation and a decrease in summer temperatures definitely contribute to the cause. There are several other conditions that are favorable for glacier development.

1. Elevation: Snowfall is generally abundant in high places, and with lower temperatures at higher elevations, glaciers are more likely to form atop mountains.
2. Latitude: The farther away from the equator, the better the conditions for formation.
3. Wind direction and topography: Winds cause snow to drift, and the contour of the land affects sunlight on the earth's surface. Conditions are more favorable for glacial formation if snowdrifts are shaded from the sunlight.

III. Glacial erosion: A glacier is a very effective agent of erosion. Glaciers are especially effective in the mountains because there is more exposed rock upon which to work.

A. Methods of erosion: In the erosional process, a glacier is a plow, a file, and a sled all at once, working through three processes.

1. Plucking: Acting as a plow, plucking is the quarrying (breaking off of rock at joints) from bedrock loosened by frost wedging under the surface of the glacier. (See Figure 18.4) The angular pieces are then picked up and carried away by the glacier.

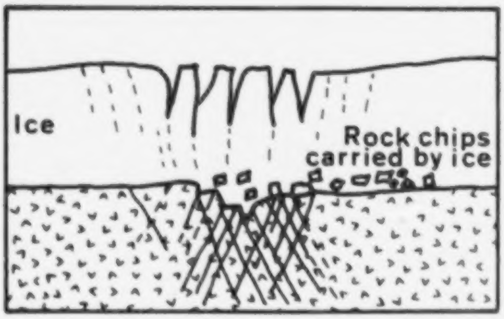


Figure 18.4. Illustrates the plucking by ice of rock from bedrock.

2. Abrading: Acting as a file, abrading is the grinding and scraping of the bedrock by the fragments of rock (those that were previously plucked) being carried at the bottom and sides of the glacier. The grooves carved in the bedrock are called striations and may range in size from hairline scratches to large gouges. Such grooves indicate the direction of the ice flow. (See Figure 18.5)

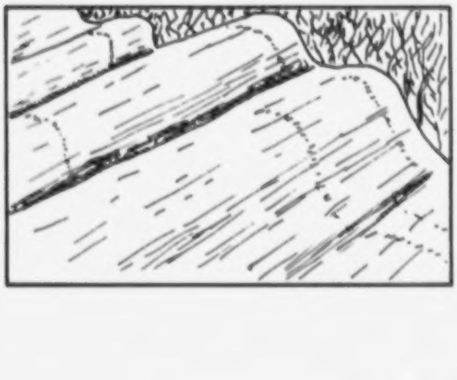


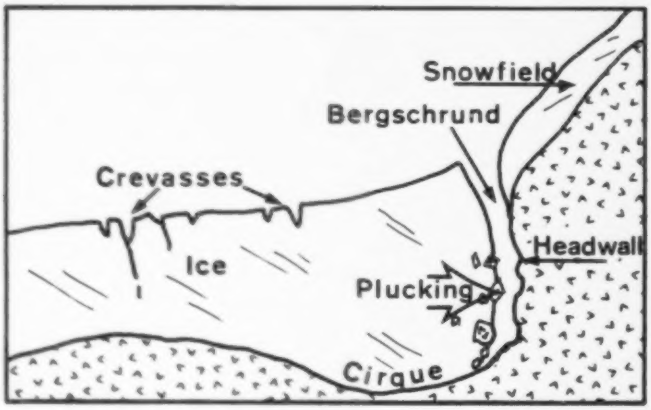
Figure 18.5. Illustrates striations that a glacier has carved in a rock exposure.

3. Sweeping: Sweeping is the "sled" portion of glacial erosion in which sediment accumulated is carried away. Loose debris is simply scooped up and held by the ice.

B. Erosional features: There are many characteristic features made by glaciers. Most of these are in mountain areas.

1. Cirque (sirk): This is a steep-walled, amphitheater-shaped depression in a mountain side formed by plucking and frost wedging (the same as frost action discussed in Chapter 14). (See Figure 18.6) The headwall is the steep cliff at the back of the cirque. The large crevasse that separates the head or beginning of the glacier from the cirque headwall is called a bergschrund. After the glacier has melted, the basin at the bottom of the cirque may become filled with water; the resulting lake is known as a tarn.

Figure 18.6. A cross-section of a cirque. Notice the plucking of the headwall.


Snowfield
Bergschrund
Crevasses
Ice
Headwall
Plucking
Cirque

2. Arete: This is a jagged ridge formed by two or more cirques positioned back to back or side by side. (See Figure 18.7) Mountain climbers often walk along the top of an arete to eventually reach the top of a glaciated peak.

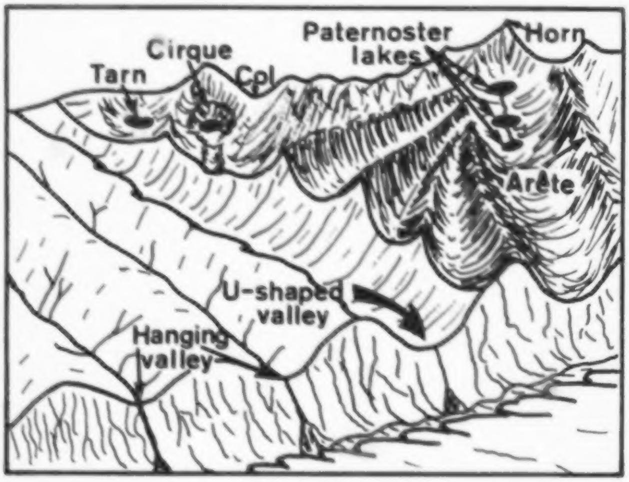

Paternoster lakes
Horn
Cirque
Tarn
Col
Arête
U-shaped valley
Hanging valley

Figure 18.7. Illustrates the various erosional features produced by glaciers. These features are best seen after glaciers have melted.

3. Col: A col is a low area in a ridge (or arete) formed when two cirques have formed on opposite sides of a ridge and eroded away part of the ridge between them. (See Figure 18.7) Cols are often used by people as a pass to travel from one mountain valley to another.
4. Horn: This is a pyramid-shaped peak formed by cirques on three or more sides. The Matterhorn in the Swiss Alps is a good example of a horn. (Guess where the name horn came from.) (See Figure 18.7)
5. Glaciated valley: When a V-shaped stream valley is eroded by a glacier, it becomes U-shaped in cross-section with a broad, flat bottom. Tributary valleys do not deepen as quickly as the main valley, so after the glacier has retreated, the tributary valley bottoms are much higher than the main valley. They are called hanging valleys. (See Figure 18.7) If a stream flows in a hanging valley, a waterfall from the hanging valley to the U-shaped valley floor results. Yosemite Falls, Yosemite National Park in California, is an example. Another glaciated valley feature is a fjord (fee owrd'). Some valley glaciers flow to the sea. At a later time, after glacial melting, the sea level rises, and water partially fills the glacial valley to become a fjord. (See Figure 18.8) Fjords make good harbors and are numerous in many northern latitude locations such as Norway, Greenland, British Columbia, and Alaska.

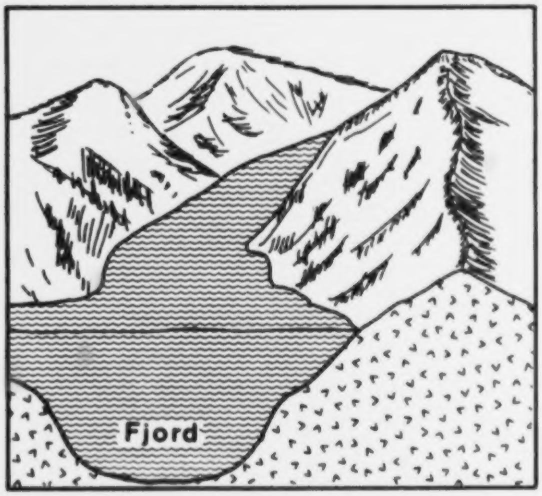


Figure 18.8. An illustration of a fjord.

6. Paternoster lakes: These are lakes that form in a series of basins carved by the glacier as it moved along the valley floor. (See Figure 18.9) Paternoster lakes form much the same way as do cirques.

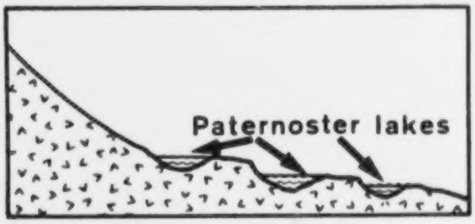


Figure 18.9. A cross-section of paternoster lakes.

7. Roche moutonnee: Literally translated as "sheep rock," a roche moutonnee is an outcrop of rock over which a glacier has flowed, leaving one side with a smooth gentle-sloping surface and the other side steep and jagged. (See Figure 18.10) The gentle slope points toward the direction from which the glacier came.

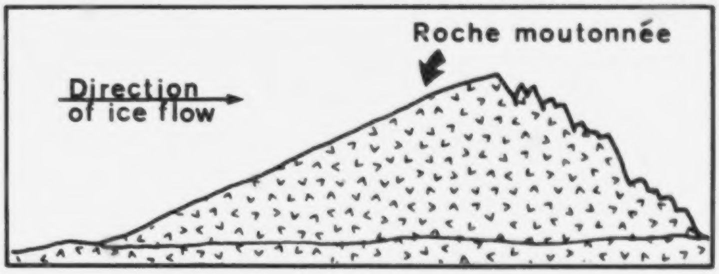


Figure 18.10. A cross-section of a roche moutonnee. The smooth side always points to the direction from which the ice came.

IV. Glacial transportation: Unlike streams, glaciers can carry great amounts of unconsolidated material. In addition, this load can be carried on the top, bottom, and sides of the glacier without being sorted. Most of the load is carried at the base and sides because these are the sites of plucking and abrasion. Much of the material on the top is talus which has fallen from the upper valley sides. Rock flour, found at the base of the glacier in meltwater, is milky-colored fine sand and silt produced by the crushing and grinding in the glacier. Huge boulders that have been carried, then dropped, are called erratics.

V. Glacial deposition: When glacial ice melts, in the zone of ablation, it releases the load it contains. Most deposition takes place in the zone of ablation.

A. Materials deposited: Any sediment deposited by glaciers is called drift. (The term drift comes from the time when what we now know to be glacial deposits were believed to be materials delivered by icebergs during the Biblical flood.)
   1. Ice deposits: Any unsorted drift deposited directly by the ice is called till. It is not sorted nor stratified.
   2. Water deposits: Glaciofluvial deposits are drift deposited by glacial meltwater. Water-laid drift that is deposited beyond the margin of a glacier is called outwash.
   3. Wind deposits: Loess (luss) is a windblown deposit of silt and clay that was blown from glacial deposits along floodplains.

B. Features deposited: Drift is capable of producing many features.
   1. Features composed of till: The following are unstratified and are deposited directly by melting glaciers.
      a) Moraine: This is either a ridge or topographic form of till that has been laid down by a glacier. The different types of moraines are named according to their positions in relation to the glacier.
         (1) End (terminal) moraine: This is an arc-shaped ridge of till that accumulates along the glacier's leading edge where the flowing ice is melting as fast as it moves forward. (See Figure 18.11) The end moraine marks the farthest point the glacier advanced.

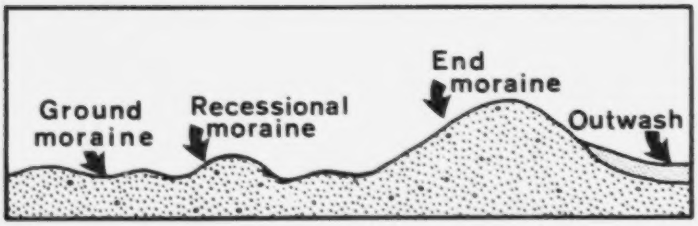


Figure 18.11. Illustrates various moraines.

(2) Ground moraine: This is widespread, thinly deposited drift with a gently undulating surface. It is also known as a till plain and is found between moraine ridges. It is deposited when the ice front melts back or retreats steadily. (See Figure 18.11)

(3) Recessional moraine: This type of moraine is like an end moraine, but it is located between the end moraine and the glacier front. It marks a pause in the regression of the glacier. (See Figure 18.14)

(4) Lateral moraine: This is a moraine that forms along the side or sides of a glacier. (See Figure 18.12)

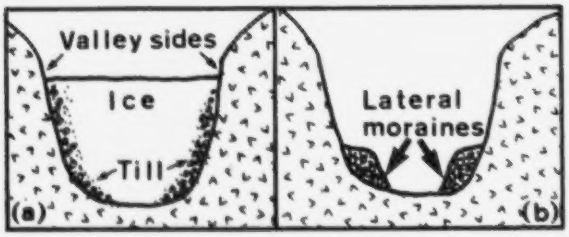


Figure 18.12. (a) is a cross-section of a valley being glaciated. Till accumulates along the edges of the glacier. (b) shows the lateral moraines left after the glacier retreated.

(5) Medial moraine: Medial moraines form from the joining of lateral moraines of two valley glaciers. The final product is a moraine in the middle of a glacier. (See Figure 18.15)

Glacial moron: A geology student who didn't read the glacier chapter.

Glacial moraine: A deposit of till resulting in a ridge or topographic form.

b) Drumlin: This is a streamlined, oval-shaped, elongated hill parallel to the direction of glacier movement. (See Figure 18.13) A drumlin has an inverted spoon shape. Its shape is opposite of a roche moutonnee, and the composition is of till instead of solid rock. Drumlin origin is not fully understood, but some believe that they form from glaciers moving over an accumulation of till, reworking it into the shape of drumlins. The most famous drumlin in the United States is Bunker Hill where a historical role was played in the Revolutionary War.

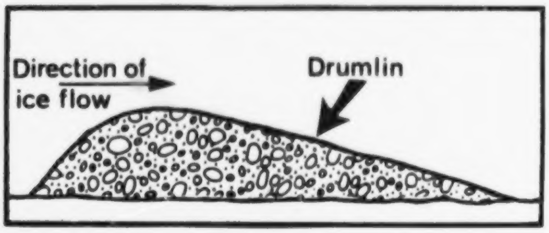


Figure 18.13. A cross-section of a drumlin.

2. Features composed of glaciofluvial deposits: The following features have been sorted during deposition by water.
   a) Outwash plain: Along the ice front, meltwater runs off the glacier in many shifting, short-lived streams that deposit a broad, flat blanket of sediment (outwash). This broad area of outwash beyond a moraine is an outwash plain. (See Figure 18.14)
   b) Valley train: Major channels for meltwaters are greatly widened and deepened during times of glacial melting and flooding. When the floods stop, the valleys are partly filled with outwash far beyond the ice margins. Such outwash deposits, largely sand and gravel, are known as valley trains. They may be both extensive and thick. For example, the long valley train of the Mississippi River valley is several hundred kilometers long. The remains of valley trains forms terraces. They are common features along the Mississippi, Missouri, Illinois, Wabash, and Ohio Rivers, to mention a few.

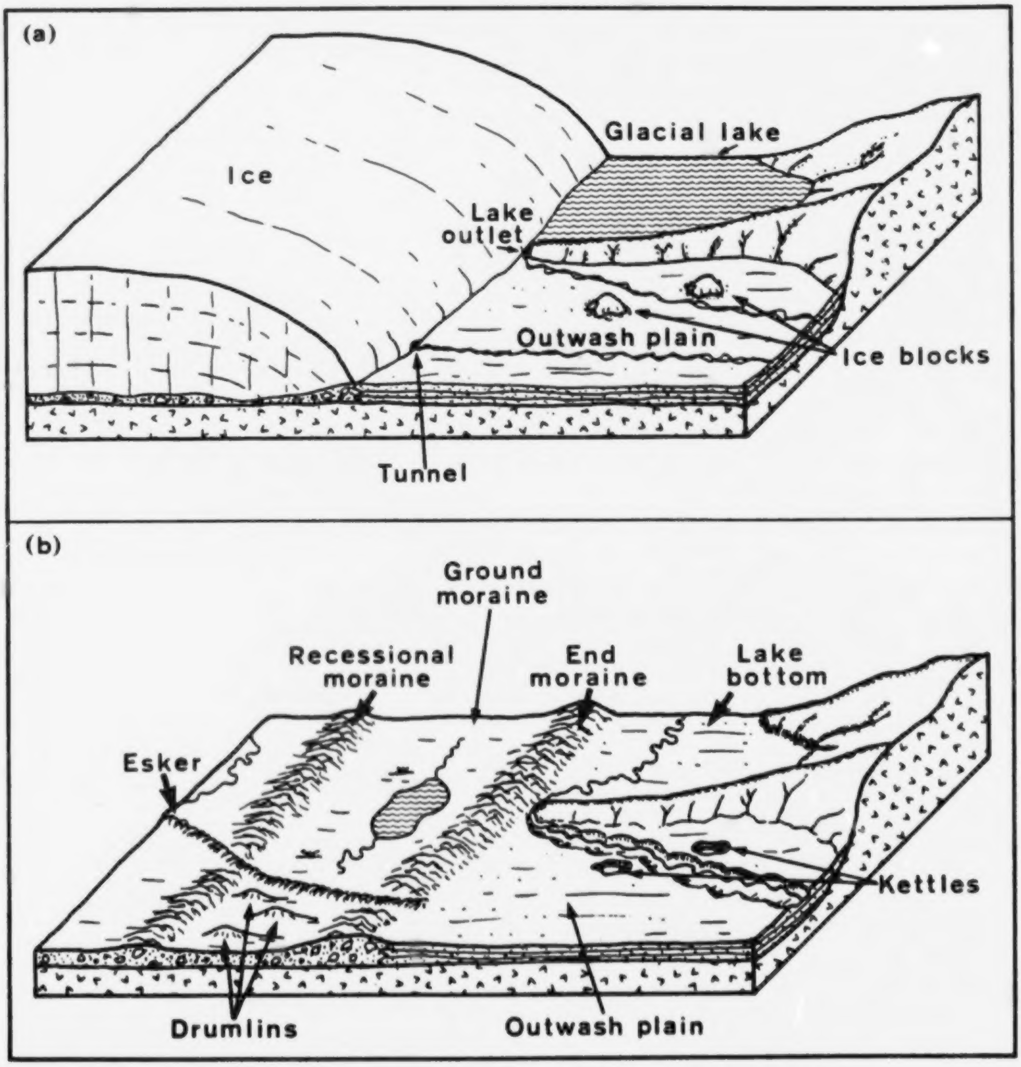

(a)
Ice
Glacial lake
Lake outlet
Outwash plain
Ice blocks
Tunnel
(b)
Ground moraine
Recessional moraine
End moraine
Lake bottom
Esker
Kettles
Drumlins
Outwash plain

Figure 18.14. (a) illustrates an area experiencing glaciation. (b) illustrates the same area after the glacier has retreated. Notice the relationship of the various features to the location of the glacier.

    - c) Kettle: This is a cavity in the outwash plain formed when an isolated chunk of ice left behind by the glacier melted and overlying material collapsed. (See Figure 18.14) Kettles can also form on ground moraines.
    - d) Esker: This is a long, narrow, sinuous ridge formed by deposits of a stream that flowed through an ice tunnel within or at the bottom of a glacier. (See Figure 18.14)
    - e) Kame: This is a cone-shaped mound of coarse glacio-fluvial deposits formed where meltwater poured through crevasses in the ice or into ponds along the edge of the glacier.
  - 3. Features formed from lake deposits: Occasionally, water becomes trapped between two moraines or between a moraine and high land in front of a glacier to form a glacial lake. Eventually, an outlet will form, thereby draining the lake and exposing thick deposits of sediment and a very flat landscape. Layered deposits of contrasting colors indicate changes of season and are called varves. It is believed that the lighter-colored silty layers were deposited in the summer, and the darker-colored clay layers were deposited in the winter.

VI. Types of glaciers: There are two types of glaciers, and their formation is dependent upon the shape of the earth where snowfall is able to accumulate.

- A. Valley glacier: The possibility exists that snow can remain on mountains year round. Therefore, with yearly accumulation, the snow may become a glacier that flows down into valleys, consequently, a valley (or alpine) glacier. A piedmont glacier forms when a valley glacier reaches the foot of the mountain and can then spread without the restriction of valley walls.
  - 1. Characteristics: Valley glaciers increase the relief of the landscape. They make the mountain features much more angular than they were before glaciation. Valley glaciers may be quite large. The Hubbard glacier, in Alaska, is 120 kilometers (75 mi) long.
    - a) Erosional features: The erosional features associated with valley glaciers include cirques, aretes, cols, horns, fjords, U-shaped valleys, paternoster lakes, and roche moutonnees.
    - b) Depositional features: Depositional features are usually found on the valley floors. They include eskers, kettles, kames, drumlins, outwash plains, valley trains, and several types of moraines. Ground moraines are present. End moraines are common, with one or more recessional moraines occurring in the valley between the valley head and end moraine. Lateral moraines grade down to the end moraines. (See Figure 18.15) Medial moraines form from the joining of two lateral moraines. (See Figure 18.15)
  - 2. Locations: Nearly every high mountain range on every continent except Australia contains valley glaciers. Most notable are probably those seen in the Alps.
- B. Continental glacier: This is a broad glacier covering a large surface area of land (sometimes referred to as an ice sheet).
  - 1. Characteristics: A continental glacier is associated with a more level, larger area of land than valley glaciers. Because the land is flatter, the continental glacier may move in all directions from the zone of accumulation. With minor exceptions, it completely covers the land. After a continental glacier has retreated, the land has been generally smoothed out.

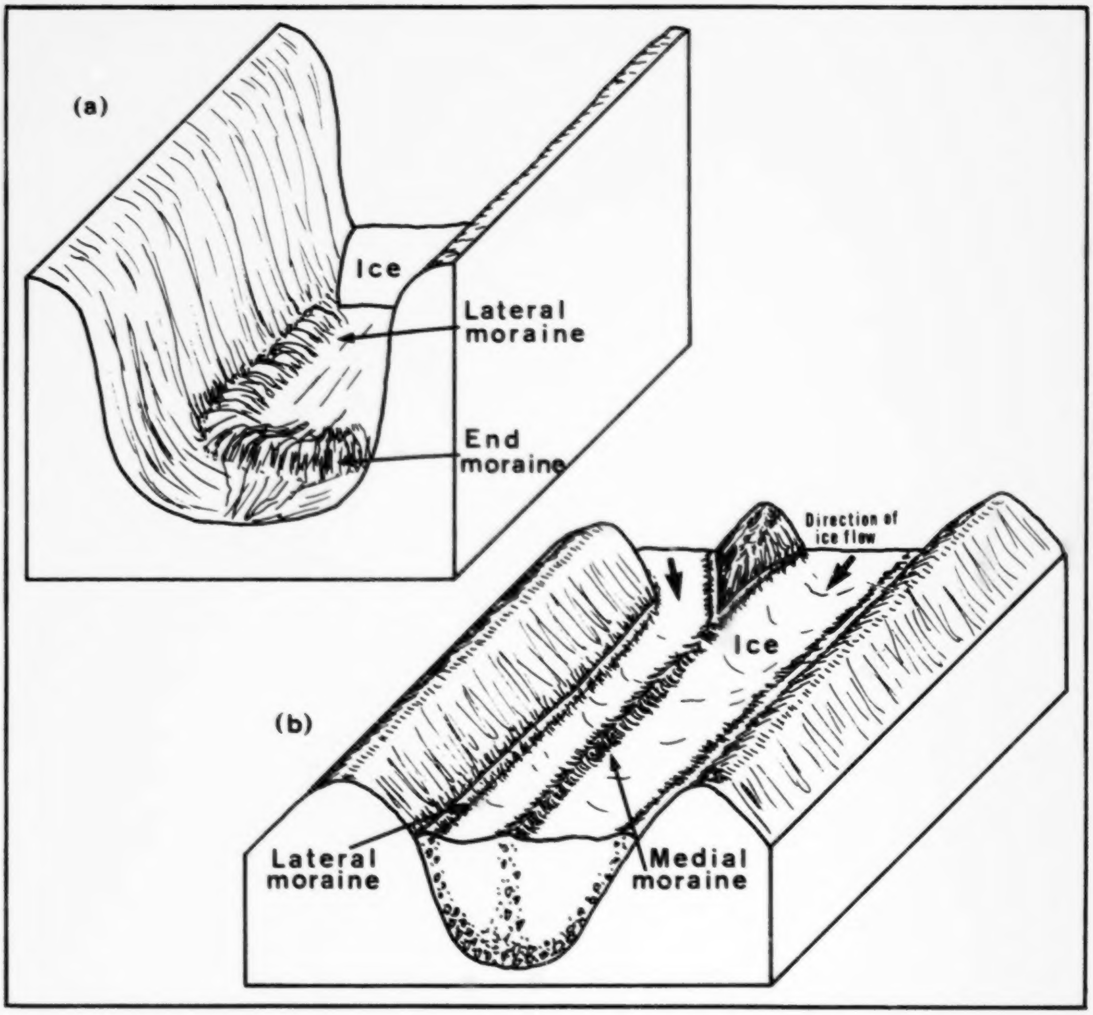


Figure 18.15. (a) illustrates the difference between a lateral and an end moraine. (b) illustrates the difference between a medial and lateral moraine.

a) Erosional features: Continental glaciers are so much larger than valley glaciers that grinding action is much more obvious. In some areas, soil and bedrock have been nearly completely removed by the glacier. A specific erosional feature formed by continental glaciers is a roche moutonnee. Scratches (striations) on remaining rock give evidence of the direction of ice flow. Glaciers also form basins which are future sites of lakes. The lake beds of the Great Lakes were molded by continental glaciers.

b) Depositional features: The amount of deposition from continental glaciers is much greater than from valley glaciers. End moraines sometimes extend for hundreds of kilometers. Ground moraines are also extensive, while lateral and medial moraines are absent. Drumlins are present and also aid in indicating the direction of ice movement. Outwash plains may be huge and contain kettles. Eskers and kames sometimes dot the landscape, while valley trains trail away from the glaciers.

2. Locations: Glaciers now in existence are found in Antarctica and Greenland where they almost entirely cover the land. Iceland has the Vatna Glacier which is a remnant of a larger ice sheet.

VII. The earth's icy past: At various times in earth's history, conditions have occurred that allowed for the development of huge ice sheets that have covered all or parts of all the continental masses. These sheets of ice have had a profound effect upon both landscape and life.

A. History of glacial activity: As with most glacial events, the more recent the event, the easier it is to understand. However, there is evidence that the pattern of glaciation began millions of years ago and continued up to the present time.

1. Early ice ages: Large ice sheets covered part of the earth as long as 700 million years ago, during the Precambrian era. Since that time, continental glaciation occurred during the Silurian, Pennsylvanian, and Permian periods.
2. The Pleistocene: The latest time of continental glaciation was in the Pleistocene epoch. The ice advances began about two million years ago, advancing and retreating in at least four major stages. In North America, the stages have been named for the areas in which they have been extensively studied. The first major advance is the Nebraskan; the second, the Kansan; the third (and largest), the Illinoian; and the latest, the Wisconsinan. The last ice retreat from the lower latitudes was approximately 12,000 years ago.

B. Evidence for worldwide glaciation: We can be certain that large areas of land were covered by glaciers by studying present glacial features and then finding similar features throughout the world where glaciation may not at first be obvious.

1. Glacial erosion: Grooves (striations) and glacially scoured bedrock provide clues to past glaciation.
2. Glacial deposition: Glacial drift is found in many regions of the world. In the younger deposits, depositional features such as moraines and drumlins may still be seen.
3. Glacial advances and retreats: There can be long periods of time between the various glacial advances. Time allows weathering of the drift to produce soils. The next glacial advance then buries the soil beneath more drift, thus leaving a record of the advances and retreats of various ice sheets. (See Figure 18.16)

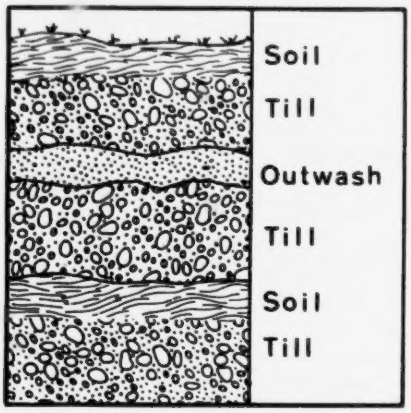


Figure 18.16. A cross-section illustrating glacial deposits and the soil layers that formed between glacial advances.

C. Causes of glaciation: The exact causes of glaciation are not known. Several theories have been considered and are discussed earlier in the chapter. The important thing to understand is that glaciation occurs in cycles, and there is no reason to assume that since "civilized" people now rule the earth, the cycle will halt.

D. Geographic extent of the Pleistocene ice sheets: In the Northern Hemisphere, several centers of ice formed in the Arctic regions. The ice spread out to cover parts of North America, Europe, and Asia. (See Figure 18.17)

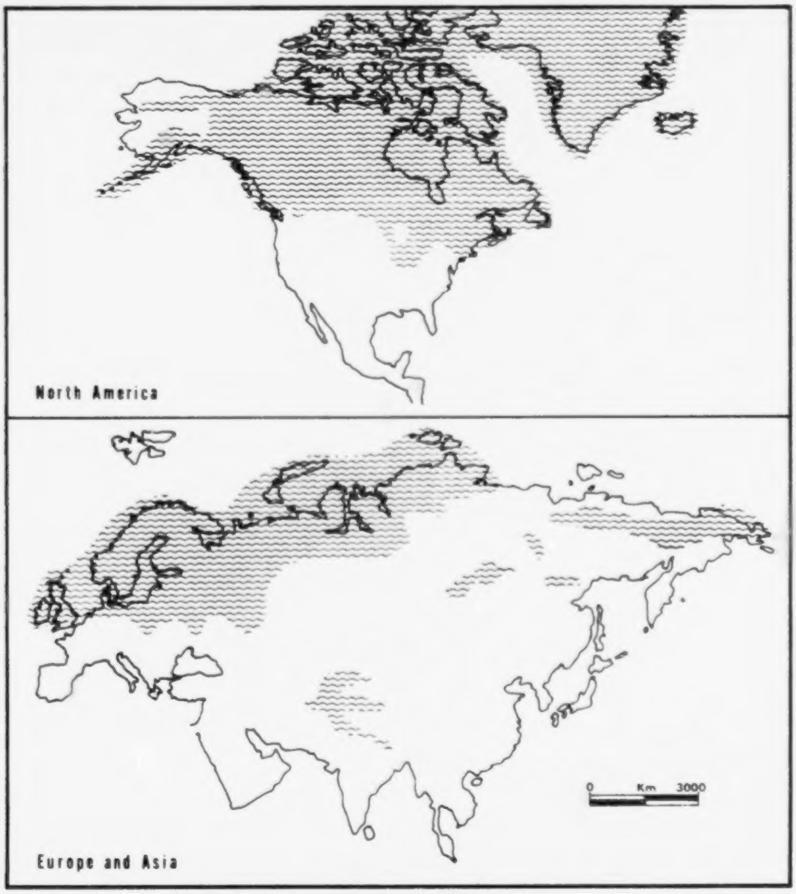


Figure 18.17. Maps of North America, Europe, and Asia show the approximate extent of Pleistocene continental glaciers.

1. Europe and Asia: Ice covered the British Isles, Scandinavia, parts of northern Europe, and much of northern Asia.
2. North America: Starting from two major centers, the ice sheets flowed in all directions. The Laurentide sheet centered in north-central Canada, the Cordilleran in Western Canada. Depending upon the topography, the sheets sometimes split into lobes (or giant tongues) of ice as they moved farther from their source regions.

a) East: The ice covered this area to the edge of the continental shelf. Included in the eastern mountains that were all covered by ice was Mount Washington. The fact the Mount Washington is 1,905 meters (6,248 ft) high provides proof that the eastern ice sheet was at least two kilometers (1.25 mi) thick. Other features include moraines as far south as Cape Cod, Massachusetts.

b) East-central and Midwest: The ice spread out to cover the northeast as far south as Pennsylvania and New Jersey. In New York, the Finger Lakes formed, gouged out of bedrock to dimensions of up to 70 meters (230 ft) long and 130 meters (426 ft) deep. Farther west, massive ice lobes advanced and retreated with a maximum extent reaching into southern Illinois and Indiana. An outstanding feature in the Midwest is the Great Lakes which, as with the Finger Lakes, formed when the glaciers eroded deep basins in the rock. One part of the midwest did, however, escape glaciation. An area known as the Driftless Area (located in northwestern Illinois, southwestern Wisconsin, and southeastern Iowa) apparently was missed by the lobes of ice and now stands as a hilly bedrock region surrounded by glacially flattened terrain. (See Figure 18.18)

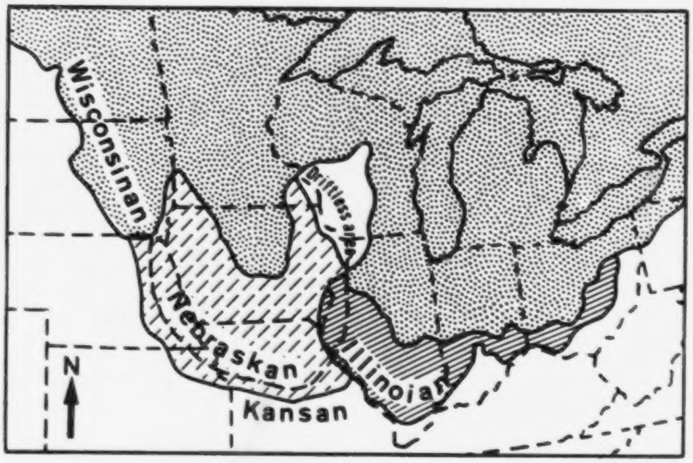


Figure 18.18. Illustrates the boundaries of the four major advances in central North America. The Driftless Area is shown in the middle of the map.

c) West: The Cordilleran ice sheet affected the high mountains of the West. Here, rather than a single continental ice sheet taking over the land, hundreds of valley glaciers grew together to form large ice sheets. The over-all effect on the landscape was one of sculpturing the mountainous regions rather than flattening the land as had occurred in the East.

E. Aftermath of the Pleistocene ice: As you can imagine, the aftermath of such a massive attack upon the land left the surface appearance much different than it had looked two million years before. In addition, the change in climate had a profound effect on the lifeforms of the region.

1. Effects on the landscape: The legacy of the ice age was amazing.
    a) Streams and valleys: The coming of the ice rerouted streams and scoured their valleys. The retreat of the ice was accompanied by the deposition of hundreds of meters of drift. This drift filled existing valleys and forced completely new drainage patterns to form. In the larger stream

valleys, wind-blown silt (loess) formed high bluffs, usually on the east side of valleys. Today, these bluffs are noticeable features along much of the Mississippi River valley in the central Midwest.

b) Lakes: The glaciers created several kinds of lakes--tarns, water-filled kettles or kettle lakes on the till and outwash plains, and (as noted before) lake basins carved out of solid rock. At times, the ice blocked streams and caused large shallow lakes to form between moraines at one end of a valley and the ice at the other. (See Figure 18.14) Large, flat, dry lake beds now exist throughout the Midwest where these glacial waters once were held. One of the largest was ancient Lake Agassiz, located in Canada, North Dakota, and Minnesota. It covered an area of 350,000 square kilometers (135,135 mi^2).

c) General topography: In the East and Midwest, the processes of erosion and deposition left the land flatter than before. Today, the flat prairies of Illinois and Iowa, in addition to the thousands of lakes in Minnesota, Wisconsin, and Michigan are proof of the work of ice. In the West, the stark scenic beauty of the Sierra Nevadas, Cascades, and Rockies owes much to the glacial ice.

d) Soils: Particularly in the central Midwest, the glaciers left behind parent materials into which developed some of the richest soils in the world. It is in loess, outwash plains, ancient lake beds, and glacial till that corn and wheat are produced in such amounts not possible anywhere else on earth.

2. Effects on life: With the coming of the glaciers, changes in life also occurred.

a) Climate: The climate varied greatly causing the ice sheets to advance and retreat. As the Northern Hemisphere grew cooler, the ice moved south, causing a change in climatic zones. The temperatures of the now warm, humid south became much like those of present-day upper Midwest and Northeast; the upper Midwest and East had weather like that found in northern Canada today.

b) Plants and animals: As the climate changed, so did the distribution and kinds of plants and animals. Tundra grew in Wisconsin, and pine forests flourished in the South. Animals moved south ahead of the ice and adapted. In addition to the southward migration, many species, such as the armadillo and opossum, arrived in North America via a "land bridge" connecting Siberia to Alaska during the Pleistocene. (See Figure 18.19) Other animals founded in North America during the epoch included the saber tooth cat, mastodon, camel, and horse, in addition to the animals that still remain here. What happened to some is still not clearly understood. It may have been the climate change, competition for living space, or pressure from early hunters. No one is sure.

c) *Homo sapiens* in North America: It would appear that the most important migration during the Pleistocene was that of humans. Anthropologists have found evidence that humans used the land bridge to migrate from Asia to Alaska, beginning from 12,000 to 15,000 years ago and then moved southward into what is now the United States. (See Figure 18.20) These ancient people were probably the ancestors of today's American Indian.

F. The end, middle, or beginning: As was mentioned earlier, scientists are not really sure what causes the cycle of glaciation. At the present time, ice sheets still exist in Greenland and Antarctica, so are we still in the "ice age"? Will the ice continue to melt, or will it again advance upon the continents and cover our northern reaches with ice a kilometer thick.

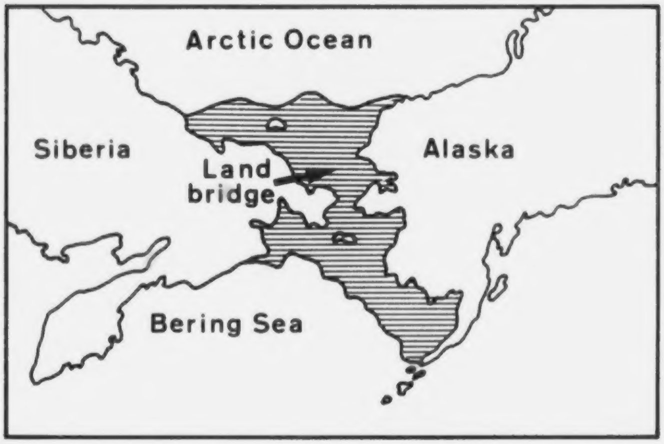

Arctic Ocean
Siberia
Alaska
Land bridge
Bering Sea

Figure 18.19. Illustrates the land bridge (the shaded area) that connected Siberia to Alaska, during times of glaciation when the sea level was lower.

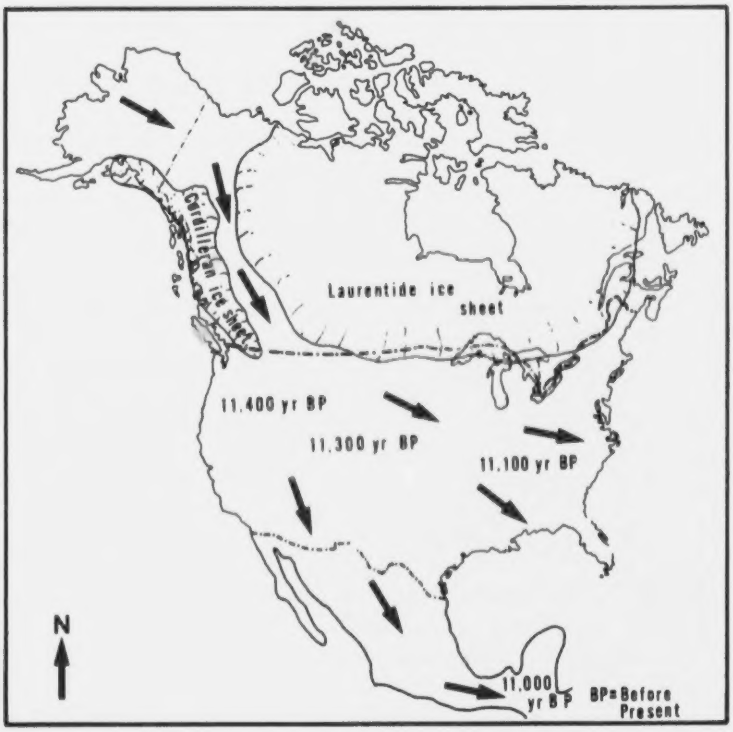

Cordilleran ice sheet
Laurentide ice sheet
11,400 yr BP
11,300 yr BP
11,100 yr BP
11,000 yr BP
BP=Before Present
N

Figure 18.20. Illustrates the general path of migration followed by early humans after they crossed the land bridge and spread across North America.

VIII. Glaciers and humanity: As with all forms of erosion, glaciers have had an effect on people. The extent of the effect depends partly upon where they live. Living in an area that has been glaciated will have an immediate effect. However, even those living in unglaciated areas consume some form of food that thrives in glaciated soil.

A. Benefits: Before glaciation, much soil present was simply a residual soil weathered from local rock debris and probably capable of supporting no more than the local population. Glaciers then came creeping along and in a mighty sweep, flattened the land and delivered the ingredients for prime farmland. Lakes, such as those depicted in Hamm's beer commercials ("the land of sky-blue water"), were really sponsored by glaciers. Groundwater is provided with an excellent home by glacial deposits. Sand and gravel are plentiful, and of course, no landscape lawn would be the same without a bold erratic.

B. Problems: Realizing the vast amounts of debris carried by a glacier makes one also realize that some area elsewhere had to give up its topsoil and bedrock. Forests were flattened, streams were eliminated, and wildlife was either forced southward or driven to extinction. Icebergs can also pose obvious problems, even to unsinkable ships like the Titanic.

C. Future: A drop of just a few degrees in the yearly average temperature could allow much ice to form. The possibility exists that the ice age is still with us, and we are simply experiencing another interglacial period. However, if the climate warmed up, the present glaciers would melt, creating a serious crisis as a result of an additional 90 meters (300 ft) of ocean water. Strangely, the warming up could cause an eventual glacial buildup because with an increase in ocean surface would come an increase in evaporation. The additional cloud cover would effectively reduce temperatures which would increase the amount of snowfall, and glaciers could grow and spread.

IX. Summary: In a location favoring snow accumulation, snow compacts and recrystallizes into glacial ice. The location of snow accumulation also determines whether the glacier will be a valley glacier, contained by a mountain structure, or a continental glacier, covering a large area of relatively level topography. As the glacier moves, it grinds, scratches, gouges, shovels, and carries anything in its pathway. When the melting and evaporation exceed snow accumulation, the glacier retreats, depositing all that it picked up on its journey. The results can be varied. Some glaciated areas can be stripped down to nothing but bare rock. Elsewhere, land is covered with cobbles and boulders. For the fortunate, slightly hilly land can be filled and leveled with deposits of parent material that will eventually weather into some of the most fertile soil in the world. Valley glaciers carve and etch mountain ranges so that their final product does not resemble the original uplifted land. All of this in terms of a person's lifespan takes many years. In terms of geologic time, however, glaciation takes place quickly and efficiently.

SEE ACTIVITY 18.1

SEE ACTIVITY 18.2

Chapter 18: Answers
(You supply the questions.)

1. Snow accumulates in the zone of accumulation. With additional pressure on top, the snowflakes beneath experience a slight increase in temperature. The tips of the flakes melt and migrate toward the center of the flake to refreeze as firn or neve. With additional melting and freezing, the firn turns into glacial ice.

2. There is the zone of accumulation where the snowfall occurs and accumulates and the zone of ablation where melting and evaporation occur.

3. There are several: elevation--snowfall is more abundant in high places so mountains are a likely location; latitude--the farthest away from the equator, the greater the likelihood of snow accumulation; wind direction and topography--wind causes drifting, and the contour of the land affects the amount of sunlight received.

4. By three processes--plucking (the "plowing" of the rock), abrading (the "filing" of the rock), and sweeping (the "sled" portion of erosion).

5. All over but mostly on the bottom and sides because these are the sites of plucking and abrasion.

6. Yes.

7. From oldest to youngest, Nebraskan, Kansan, Illinoian, and Wisconsinan. The Nebraskan and Kansan are not subdivided because later glaciers destroyed much evidence of what occurred during these stages.

8. It formed by the weathering of drift and loess. Some were destroyed by later glacial advances, but the ones that survived aid in determining the glacial history.

9. The Illinoian stage.

10. It depends upon where the location is. Some areas were scraped down to bedrock while others were left with a rich soil cover.

11. No

12. It could happen with a drop of a few degrees in average yearly temperatures.

13. Occasionally

Unit V: External Processes

CHAPTER 19: Wind Action

I. Introduction

II. Wind Transportation
  A. Suspended Load
  B. Bed Load

III. Wind Erosion
  A. Environments
    1. Desert
    2. Shoreline
    3. Stream Margin
    4. Area of Loose Sandstone
    5. Glacial Outwash Plain or Valley Train
    6. Area of Volcanic Activity
  B. Types of Wind Erosion
    1. Deflation
      a) Lag Deposit or Desert Pavement
      b) Blowout
    2. Abrasion

IV. Wind Deposition
  A. Dunes
    1. External Dune Structure
    2. Internal Dune Structure
    3. Dune Migration
    4. Types of Dunes
      a) Traverse Dunes
      b) Longitudinal or Seif Dunes
      c) Barchan Dunes
      d) Parabolic or Blowout Dunes
    5. Dune Composition
  B. Loess

V. Environmental Aspects
  A. Benefits
  B. Hazards

VI. Summary

Related Activities

Vocabulary

Analyze hypothetical wind-related problems and suggest possible solutions to these problems.

Determine dune types and formation.

Problems and questions

Wind Action Geo Facts

On the southern shore of Lake Michigan, westerly winds have caused sand dunes to move across a forest floor at Indiana's Dune Park.

It is said that every square kilometer of the earth's surface contains dust from every other square kilometer.

Dust from the Sahara Desert occasionally falls in England.

The bottom portion of telephone poles has been chewed away by the sand in wind storms. Cars have been sandblasted down to bare metal.

The wind removes the fine material that streams and glaciers have stockpiled for later disposal at sea.

Wind action on Mars is significant because of the lack of vegetation and water.

In the last 50 years, people have given up 9,200,000 square kilometers (400,000 mi^2) to deserts.

Deserts make up one-third of the world's landscape.

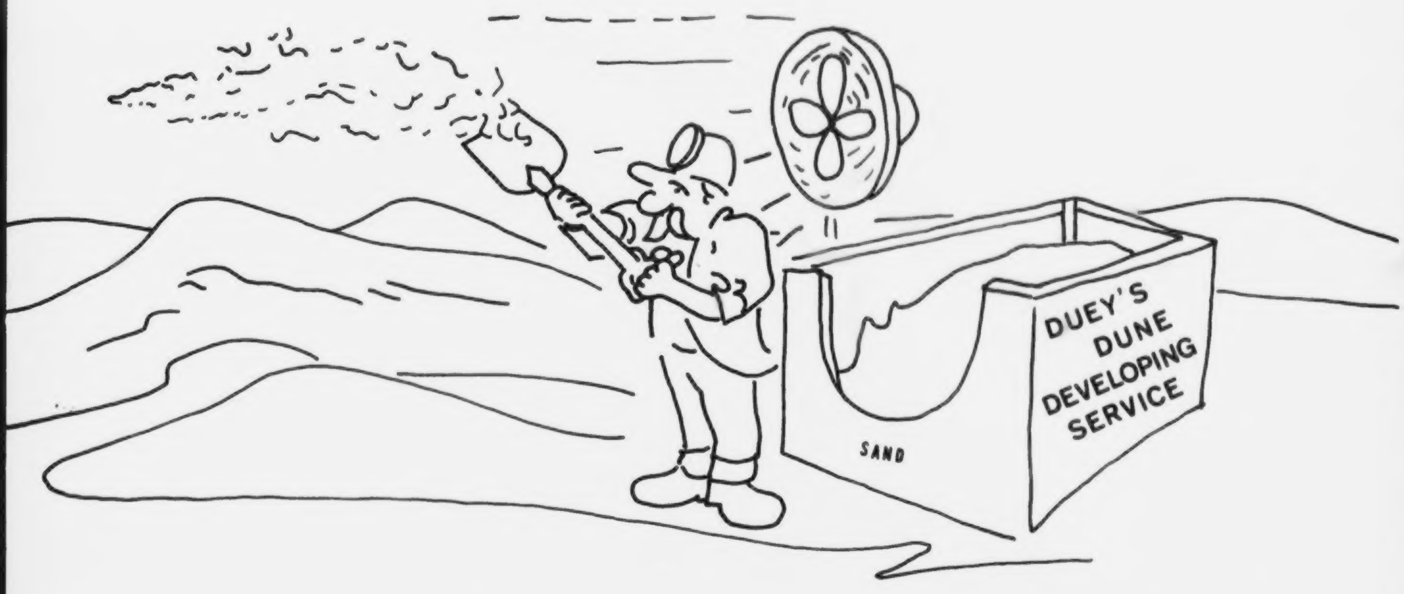
Winds are not the major sculptor in deserts--running water is.

Wind action dies out above about 1.2 meters (4 ft).

Deserts are less than one-tenth sand. They are mostly barren rock.

Sand dunes move from a few meters to 76.3 meters (250 ft) per year.

The rain of humid regions is one of the chief factors in removing dust from the air.



Chapter 19: Word List

Abrasion
Angle of repose
Barchan dune
Bed load
Blowout
Blowout dune
Cross-bedding
Deflation
Desert
Desert pavement
Dune
Eolian deposit
Facet
Fixed dune
Lag deposit
Lag gravel
Leeward slope
Loess
Longitudinal dune
Parabolic dune
Saltation
Slip face
Suspended load
Traction
Traverse dune
Ventifact
Wind
Windward slope

Straight Terms

Crescent
Disintegrate
Eddy
Migrate
Vulnerable

UNIT V: EXTERNAL PROCESSES

Chapter 19: Wind Action

I. Introduction: Wind is air moving from an area of high pressure to an area of low pressure. Of the three agents of erosion (water, glaciers, and wind), wind is the least effective in wearing down the land. It occurs only in the most specific of conditions. However, given the perfect conditions, the wind possesses the power to sweep up particles of the earth, carry them, and deposit them into sometimes creative shapes and sizes. It is about these aspects of wind action that you will be studying in this chapter.

II. Wind transportation: As air moves along the surface of the ground and then sweeps upward, it is able to move or transport particles of the earth. This process is much the same as transportation by running water in the following ways.

A. Suspended load: This is the temporary support of fine sediment such as clay or silt by eddying wind currents. The clay and silt particles are small enough to be held in the air for some distance before resettling. The finest particles of the suspended load can be swept hundreds to thousands of meters into the air, depending upon the velocity. If the wind is strong and large clouds of dust are being carried and you are there, you are experiencing a dust storm. Sand-sized or larger particles are too heavy to be supported by wind, so you can understand that sand storms really do not exist.

B. Bed load: The bed load is the lower layer of particles carried above the ground by the wind. The bed load can be clearly seen during high winds. It is rarely more than one meter (3.3 ft) high and consists primarily of sand immediately above the ground and grades into the suspended load. Sand grains can get into the air by saltation (movement resulting from jumping or bouncing of particles). Gusts of wind start particles moving. As they strike the ground at low angles, they either hop again or strike other particles causing them to jump. (See Figure 19.1) The remaining portion of the bed load travels by traction (the rolling or sliding along of particles).

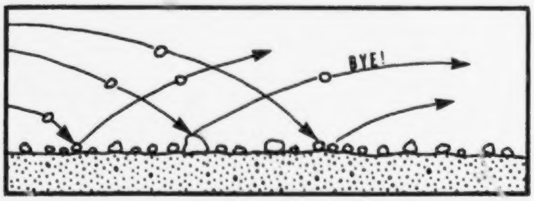
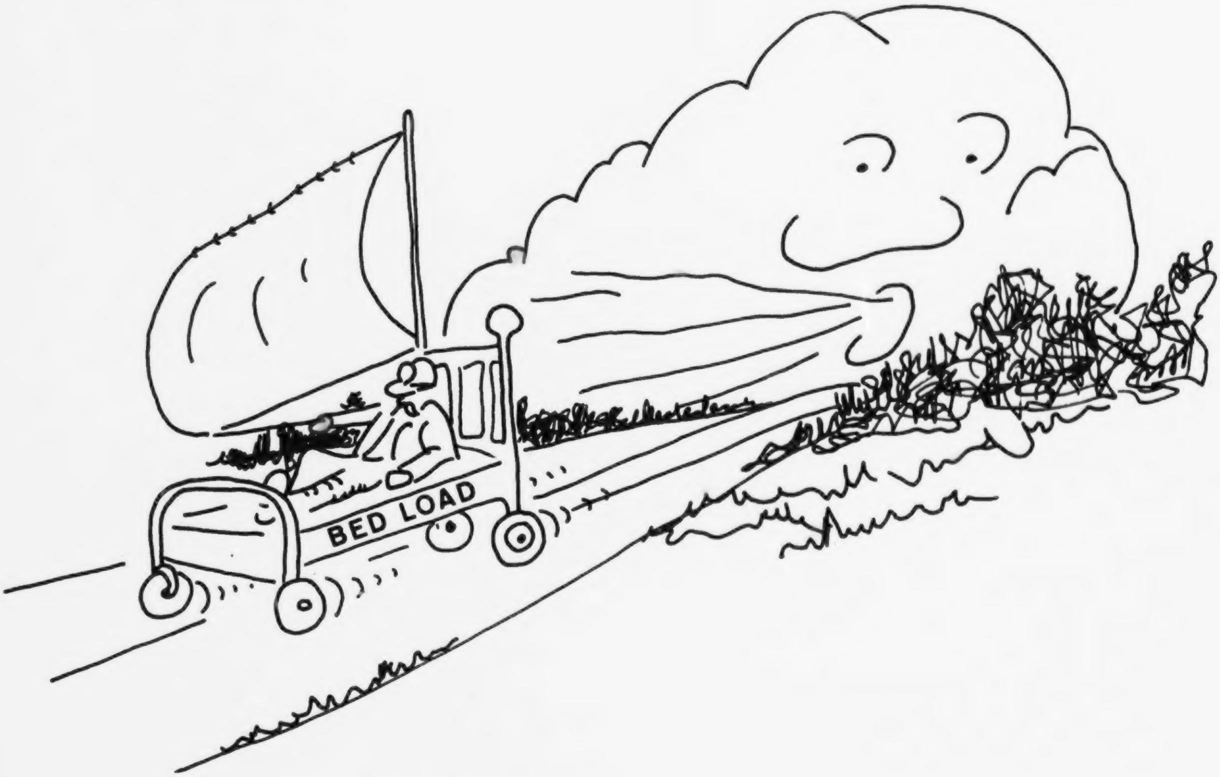


Figure 19.1. Illustrates the movement of individual particles as they travel by the process of saltation.



III. Wind erosion: Erosion by wind is considerably less than that of water and ice simply because the wind is much less dense. In fact, air is about 1,000 times less dense than water. As a result, it is only in limited regions that factors are such as to favor wind erosion.
   A. Environments: Wind erosion takes place in those areas having little vegetation; those having a consistent wind of modest velocity; those receiving only a small amount of rain; those where the topsoil has been disturbed; or those having a silt, sand, or clay supply. There are several locations where these conditions exist.
      1. Desert: A desert is an area that is able to support a very limited number of plants and animals. It is probably the most well-known area for wind action because it is dry and has little vegetation.
      2. Shoreline: The beaches of seas and large lakes are susceptible to wind action because of a large supply of sand, primarily.

3. Stream margin: The area along streams, especially in semi-arid regions, can experience wind action. Good examples include the Platte, Arkansas, and Missouri Rivers across the Great Plains.
4. Area of loose sandstone: Sometimes, loose sandstone will disintegrate to supply sand. This has occurred in the Sand Hills of western Nebraska.
5. Glacial outwash plain or valley train: As you recall, glacial outwash is fine material and can be deposited as loess.
6. Area of volcanic activity: Volcanic explosions can simply inject dust into the air where it can be carried for varying distances, depending upon the wind.

B. Types of wind erosion: There are several ways the wind can erode.

1. Deflation: This is the process of removing small particles by the wind. Through this process, the surface of the earth is slowly lowered. Deflation is most common in dry, unvegetated areas. It abruptly stops when the water table is reached. Two features can be created as a result of deflation.
    a) Lag deposit or desert pavement: These are names given to a surface layer of pebbles or boulders left after the sand and silt have been blown away, or deflated. (See Figure 19.2) Lag gravel is the term given to the remaining pebbles and boulders of the lag deposit or desert pavement. As the name desert pavement implies, this feature is confined to deserts. The stony deserts of northern Africa have resulted from deflation removing the sand to produce a desert pavement.

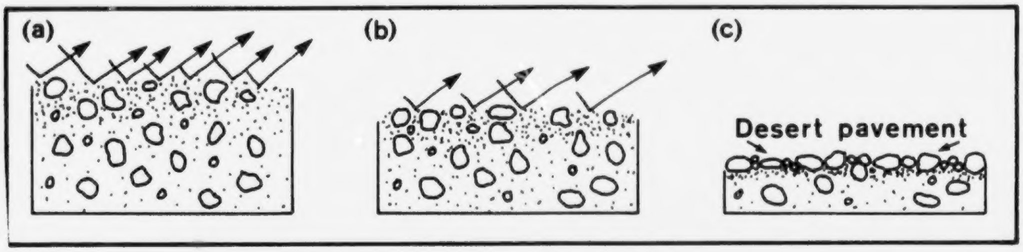


Figure 19.2. Illustrates three progressive stages in the creation of a desert pavement. (a) and (b) have deflation occurring. (c) has no further deflation.

    b) Blowout: This is a basin or depression formed by deflation. Blowouts are found in sandy areas or in areas of weak sediment where the natural plant cover has disappeared. Such features are found in the Great Plains where, locally, blowouts are known as "buffalo wallows." Examples include Danby Playa in the Mohave Desert, and Big Hollow near Laramie, Wyoming. Big Hollow is 15 kilometers (9-1/2 mi) long, 5 kilometers (3 mi) wide, and 91 meters (300 ft) deep, proving that blowouts can be large (or proving that vast numbers of buffalo can wallow in one area).

2. Abrasion: This is the blasting of wind loaded with sand against rocks. It is similar to abrasion by running water. It polishes, pits, grooves, and shapes the rocks influenced by it. Abrasion does not generally occur more than one meter (3.3 ft) above the earth's surface. Because sand is predominantly quartz and because quartz is such a hard mineral, abrasion can be quite effective. It causes erosion near the bases of cliffs. Cars caught in a dust storm can be sandblasted down to bare metal, with the windshield turned into frosted glass (an accomplishment for the *Guinness Book of Records* but a heartbreaker in reality). Loose stones and bedrock surfaces found in desert areas are also sculptured by abrasion to form ventifacts--polished, sometimes greasy-looking

rocks that can have facets (flat polished surfaces) which are separated by sharp angles. (See Figure 19.3) They tend to resemble Brazil nuts.

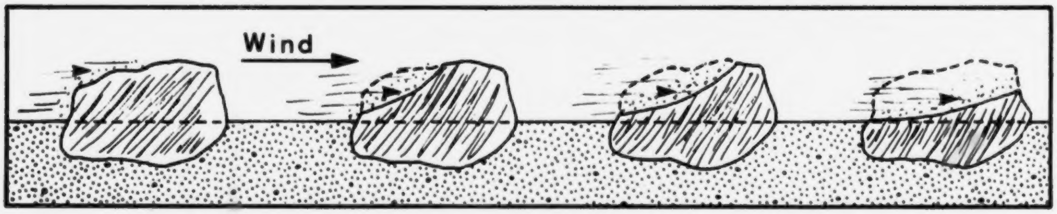


Figure 19.3. Illustrates four stages in the formation of a ventifact by wind abrasion.

IV. Wind deposition: The velocity of the wind and the presence or absence of water will determine the capacity of the wind to carry particles of earth and rock. A high wind velocity and the absence of water are favorable for more carrying power. If the wind decreases in velocity or if it rains, the carrying power is reduced, and the particles are deposited. Materials deposited by the wind are called eolian deposits. They can be found in several forms.

   A. Dunes: These are low, rolling, unsymmetrical hills of sand (usually), produced when the wind meets an obstacle which disrupts the flow of air, causing the wind to drop its load of sand. As an obstacle is encountered by the wind, the wind flows over and around the obstacle. However, a pocket of slower-moving air is left behind the obstacle, causing sand to be dropped, and forming a mound. Dune formation depends upon a strong prevailing wind, a source material, a location for deposition, and a cause for deposition.

      1. External dune structure: With the presence of a mound, additional sand accumulates to form a dune. A dune has a steep slope and a gentle slope. (See Figure 19.4) The gentle slope is called the windward slope; the steep slope is the leeward slope. New material is carried up the windward slope and falls down the leeward slope. Because sand slips down the leeward slope, this side is also called the slip face. The angle of repose is the angle of the slip face with the ground surface. Sand accumulates on the slip face until the angle of repose is 34 degrees. Once this angle is established, additional sand simply drops down the unstable slope, thus maintaining the angle. The angle of the slope on the windward side varies, depending upon the strength of the wind. However, it is never as large as the angle of repose. The windward slope always indicates the direction from which the wind came.

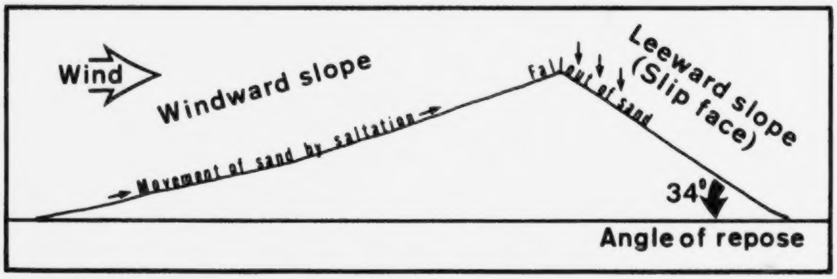


Figure 19.4. Illustrates the development and structure of a dune.

2. Internal dune structure: As the sand drops over the crest or top of the dune, it forms cross-bedding (layers that lie at an angle to other layers). (See Figure 19.5) Cross-bedding occurs because of the wind changing velocity and direction. It is clearly seen in some sandstones originally deposited by the wind.

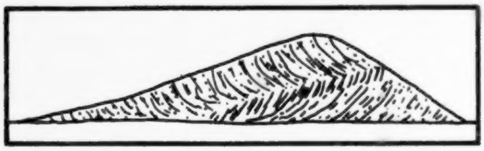


Figure 19.5. An illustration of cross-bedding.

3. Dune migration: After dunes have formed, they tend to migrate downwind (the same direction the wind is blowing). Sand is carried up the windward slope and is deposited on the leeward slope. By continually experiencing this process, the dune moves or migrates. When vegetation has an opportunity to sink its roots into some part of the dune, it is able to reduce or stop the migration. Once the dune has some form of anchor, it becomes smaller in size and can become completely covered with vegetation. A dune that is no longer able to migrate is called a fixed dune.
4. Types of dunes: Dunes can form into several different shapes. The shape depends partially on the strength of the wind; however, the deciding factors are only partly understood.
    a) Traverse dunes: These are long, wave-like ridges of sand with furrows in between that form at right angles to the wind direction. (See Figure 19.6) Traverse dunes usually form in environments where there is a large sand supply, a constant wind direction, and a lack of vegetation. They are most commonly found near coastal areas of lakes or streams or on the floors of deserts.

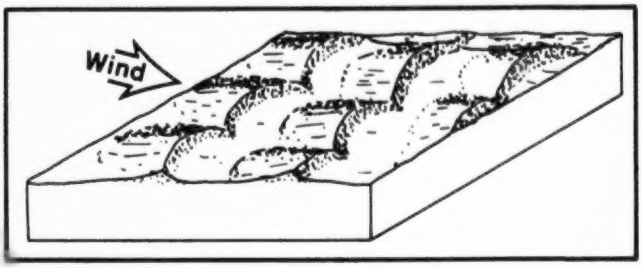
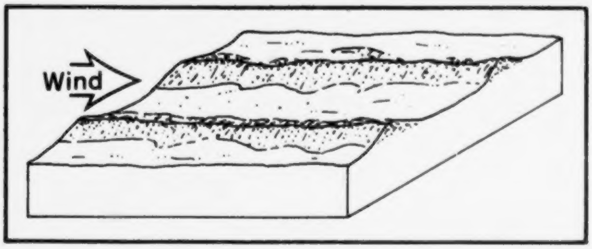


Figure 19.6. And now presenting a traverse dune.

    b) Longitudinal or seif dunes: These are long, parallel ridges of sand that also run parallel to the direction of the wind. (See Figure 19.7) They form with a limited supply of sand, with a gentle prevailing wind from one direction and an occasional strong wind from another direction, and with few obstructions. Northern Africa, Arabia, and central Australia are locations exhibiting examples of longitudinal dunes.

Figure 19.7. A longitudinal dune.



c) Barchan dunes: These are crescent-shaped dunes. The tips of the dune point downwind. (See Figure 19.8) They are the rarest form of dune, occurring in clusters and forming on flat surfaces. They require only a limited supply of sand, a constancy of wind direction, and a wind velocity of moderate speed. The sand grains tend to travel not only up and over the dunes but also around the tips.

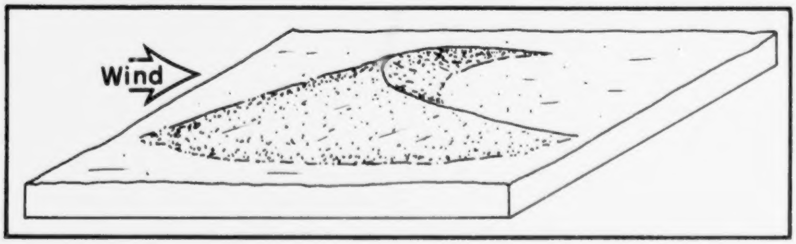


Figure 19.8. A barchan dune!

d) Parabolic or blowout dunes: These are similar in shape to the crescent-shaped barchan dunes, but the tips of these dunes point upwind (toward the direction from where the wind is blowing). (See Figure 19.9) Parabolic dunes are commonly found along shorelines and are accompanied by strong winds. They are associated with a partial cover of vegetation. They frequently form along the leeward and lateral sides of a blowout and are composed primarily of the sand removed from the blowout.

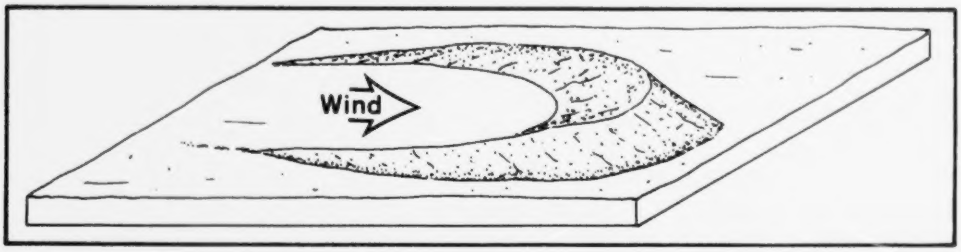


Figure 19.9. And finally, a parabolic dune.

5. Dune composition: Dunes are composed, for the most part, of sand-sized particles. Quartz is the most common mineral in sand; therefore, it is the mineral that most frequently composes dunes. However, they can be composed of calcite, like the dunes found in Bermuda, or gypsum, like the dunes found at White Sands National Monument in New Mexico. Strange as it may seem, there are even clay dunes along the Gulf Coast.

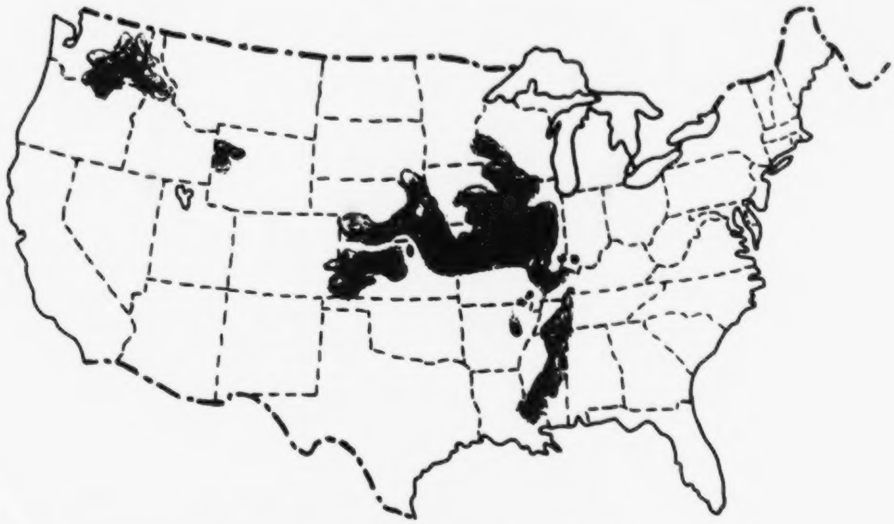


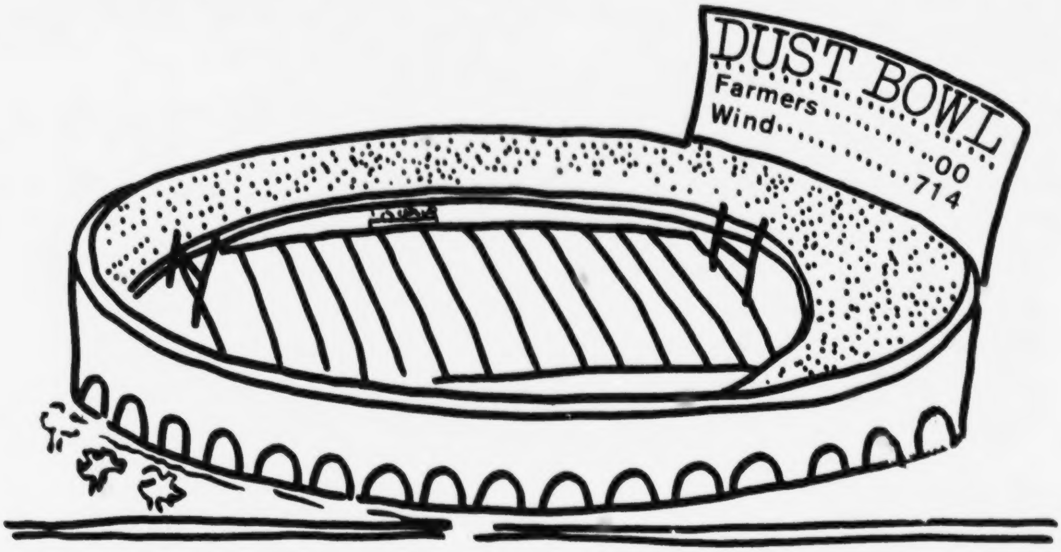
Figure 19.10. Illustrates the general extent of loess deposits in the United States.

B. Loess: As you recall, loess is windblown silt, sometimes accompanied by clay and fine sand. Most loess deposits are associated with glacial outwash. The areas of loess deposits in the United States are outlined in Figure 19.10. The Mississippi River valley served as a source for loess during the Pleistocene. In some Illinois counties, wells have been drilled through 15 meters (50 ft) of loess. Near the Mississippi River, loess deposits are characterized by embedded snail shells and calcium carbonate nodules. These features disappear farther from the river as the loess thins in its extension eastward across the state. While loess deposits in the United States may seem extensive, actually, the world's greatest loess deposits are found in China. There, the deposits are several hundred meters thick, and it is believed that their source is the Gobi Desert in Mongolia.

V. Environmental aspects: The wind gives, and the wind takes away. Through these processes, people sometimes benefit and sometimes suffer.

A. Benefits: Highly productive grasslands and prairie soils continually have their essential mineral trace elements renewed by the settling of dust that has been windswept from other areas. The irony of this is that if the source areas of the dust were stabilized, the areas that were enriched by the settling dust would require fertilizers. Additional benefits include the many dunes that provide valuable raw material to industry, especially in the foundry business of making cores and molds. Loess deposits have filled in hilly land and have provided the base for excellent soils that are silty and easy to plow. In China, Europe, and, to a lesser degree, United States, houses have been built of loess in much the same way that adobe is used. Another benefit derived from wind deposits is in the form of oases. And last, but not least, dunes provide excellent locations for operating dune buggies. (Where could they have gotten the term "dune buggy"?)

B. Hazards: Dunes may be considered a hazard to anyone that has had an injury from a dune buggy accident. Of a more serious nature, migrating dunes have no respect for anything in their way. As a result, they can simply engulf most any obstacle in their path, even a house. Probably the most familiar hazard, though, is the situation that resulted in the Dust Bowl in the 1930's. Leading up to the time of the Dust Bowl, farmers plowed up soil and had little idea of the devastating consequences. They exposed the formerly grass-covered soils of the Great Plains (combined with the essential ingredients of a dry climate and an average wind velocity great enough to move sand grains and to keep coarse silt grains in suspension) producing disaster to many. Today, even with the lesson of the Dust Bowl reminding us of the value of practical conservation measures, some farmers still plow their fields in the fall, exposing their most valuable resource to wind action during the winter. (And the proof, friends, is in the brown snow that gently blankets us.) Western and southwestern United States suffer severely during times of drought because of the removal of soil.



VI. Summary: Relative to carrying capacity of the wind, one finds that the amount of sediment actually carried by the wind is only a fraction of one percent. Because the air is rarely fully loaded to its capacity, wind is simply not an effective agent of erosion. Since it does affect the earth's surface, it must be considered. Performing in much the same way as running water, it transports fine sediment by suspension and heavier sediment by saltation and traction. The wind most actively erodes desert area but it can attack shorelines, stream margins, areas of loose sandstone, and areas of glacial outwash. It erodes the earth by deflation to produce lag deposits and blowouts, and by abrasion. When the carrying power is reduced, the wind deposits its load to be molded into various kinds of dunes if the content is sand, or loess if the content is silt. As with all of the aftereffects of erosion, people must learn to adapt to the benefits and hazards created by nature.

SEE ACTIVITY 19.1

SEE ACTIVITY 19.2

Chapter 19: Problems and Questions

1. Name the conditions of an area that could make it susceptible to wind action.
2. Discuss the two (2) ways the wind is able to carry sediment.
3. Give four (4) locations where wind erosion can easily exist.
4. Discuss the two (2) ways the wind can erode.
5. Name the two (2) factors that determine the carrying power of the wind.
6. Describe how dunes form.
7. Illustrate and describe the structure of a dune.
8. Describe how cross-bedding results.
9. Describe the four (4) different kinds of dunes.
10. Of what mineral are dunes composed?
11. Describe loess.
12. Discuss the benefits and hazards of wind action.
13. Using one or more of the wind actions discussed, explain how the wind can help fertilize our farmlands.
14. Using one or more of the wind actions discussed, explain why our furniture must be dusted weekly.

Unit V: External Processes

CHAPTER 20: Ocean and Wave Action

- I. Introduction

- II. Oceans
  - A. General Characteristics
    - 1. Area
    - 2. Range of Depth
    - 3. Chemical Composition
    - 4. Range of Temperature
  - B. Shape of the Ocean Floor
    - 1. Continental Margin
      - a) Continental Shelf
      - b) Continental Slope
      - c) Continental Rise
    - 2. Deep Ocean Floor
      - a) Abyssal Plains
      - b) Mid-oceanic Ridges
      - c) Trenches
      - d) Seamounts
      - e) Guyots
  - C. Ocean Sediment
    - 1. Origin of Sediment
      - a) Land
      - b) Ocean
        - (1) Biologic
        - (2) Volcanic
      - c) Outer Space
    - 2. Types of Sediment
      - a) Terrigenous Material
      - b) Ooze
      - c) Red clay
  - D. Movement of Ocean Water
    - 1. Currents
      - a) Subsurface Currents
      - b) Surface Currents
      - c) Longshore Currents
    - 2. Tides
    - 3. Waves
      - a) Wave Structure
      - b) Wave Motion
      - c) Wave Refraction
      - d) Breakers

- III. Shoreline Development
  - A. Shoreline Erosion
    - 1. Erosional Processes
      - a) Hydraulic Action
      - b) Abrasion
      - c) Solution

        2. Erosional Features
            a) Sea Cliff
            b) Wave-cut Bench
            c) Notch
            d) Sea Cave
            e) Sea Arch
            f) Sea Stack
        3. Duration of Erosion
    B. Shoreline Transportation
    C. Shoreline Deposition
        1. Beaches
        2. Sand Bars
            a) Irregular Shorelines
            b) Regular Shorelines
    D. Shoreline Evolution

IV. Classification of Shorelines
    A. Active Shorelines
        1. Submergent
        2. Emergent
    B. Neutral Shorelines
        1. Delta Formation
        2. Volcanic Activity
        3. Coral Reefs
    C. Compound Shorelines
    D. Other Classifications
        1. Primary/Secondary
        2. Regular/Irregular

V. Shorelines and Society
    A. Benefits
    B. Hazards
    C. Solutions

VI. Summary

Related Activities

Vocabulary

Identify wave action on topographic maps.

Identify wave action problems, and determine solutions to these problems.

Problems and questions

Wave Action Geo Fact

If continents did not continually rise, the ocean would cover the entire earth.

Chapter 20: Word List

Washed Up Words

- Abyssal plain
- Backwash
- Bay
- Baymouth bar
- Beach
- Breaker
- Calcareous ooze
- Compound shoreline
- Continental margin
- Continental rise
- Continental shelf
- Continental slope
- Current
- Emerged shoreline
- Guyot
- Headland
- Hook
- Inlet
- Irregular shoreline
- Lagoon
- Longshore current
- Mid-oceanic ridge
- Notch
- Ocean
- Ocean basin
- Offshore bar
- Ooze
- Pelagic
- Red clay
- Rip current
- Salinity
- Sand bar
- Sea arch
- Sea cave
- Sea cliff
- Seamount
- Sea stack
- Shoreline
- Siliceous ooze
- Spit
- Straight shoreline
- Submarine canyon
- Submergent shoreline
- Surf zone
- Terrigenous
- Tide
- Tombolo
- Trench
- Undertow
- Wave
- Wave crest
- Wave-cut bench
- Wave height
- Wave length
- Wave refraction
- Wave trough

HEADLINE: Geologists Meet to Study Shoreline Problems in Hawaii

UNIT V: EXTERNAL PROCESSES

Chapter 20: Ocean and Wave Action

I. Introduction: You have probably been aware of oceans since they were perhaps first introduced to you in such nursery rhymes as "Rub a dub dub, three men in a tub." Aside from the fact that they cover nearly two-thirds of the earth's surface and are therefore prominent just in size, they influence our lives in many ways. Created by internal processes, ocean basins (the floors of oceans) were first formed and then became filled with water. The water in the ocean basins began to move, and the huge amount of water involved created a strong external process that now designs and sculptures the edges of landmasses. This chapter is going to give you a general overview of oceans themselves, and it is going to discuss the effects of ocean water on the aging of land.

II. Oceans: Geologically speaking, the ocean is the body of salt-water that occupies nearly two-thirds of the earth's surface. It exerts a large influence on humanity by being our ultimate source of water, regulating climates, and supplying food, to mention a few. It is also important geologically. For that reason, we now introduce you to--the ocean.

- A. General characteristics: In case you have any difficulty recognizing the ocean, there are several characteristics that will aid you.
    1. Area: An exact total of 71 percent of the earth's surface is ocean water. In the Northern Hemisphere, 61 percent of the surface is water, and 39 percent is land. In the Southern Hemisphere, 81 percent is water, and 19 percent is land. Although the ocean is one continuous basin, it has been subdivided into oceans, such as the Atlantic and Pacific, and seas, such as the North Sea. These divisions are merely for geographical purposes by people.
    2. Range of depth: The average depth of the ocean is 3.8 kilometers (2.4 mi). However, there are great variations. The most awesome is in the Nero Deep in the Marianas Trench where the depth is about 11 kilometers (6.8 mi). (Compare that to Mount Everest which is just short of being nine kilometers high.)
    3. Chemical composition: Ocean water contains dilute (weak) solutions of many salts, the most common of which is sodium chloride. This salinity amounts to about 3.5 percent by weight of ocean water. In addition, it contains most of the gases found in the atmosphere, as well as over 40 other chemical elements found in solution.
    4. Range of temperature: Temperatures of surface or near surface ocean water vary from nearly 32° centigrade (90°F) in the Persian Gulf to -2° Centigrade (28°F) in polar areas. Since cooler water sinks, temperatures decrease with depth.
- B. Shape of the ocean floor: The ocean floor is not just a gently sloping depression. It is shaped by deep trenches, high peaks, and large plains.
    1. Continental margin: This is the region that extends from the coastal shoreline (the line along which the land meets the sea) to the deep ocean floor. It represents a transition from the high continents to the deep ocean. (See Figure 20.1)
        - a) Continental shelf: This is a gently sloping, relatively shallow surface along the edges of continents. The width of continental shelves varies greatly from hundreds of kilometers off Siberia and Brazil to a complete absence along the west coast of South America. The shelf along North America ranges from several kilometers in width offshore in eastern United States to only a few kilometers near California. The width of the continental shelf seems to be linked to the kind and age of plate activity occurring in the adjacent ocean basin. If a deep oceanic trench is nearby, continental sediment is deposited in the trench, and there is little shelf development. Where large shelves exist, sediment accumulation occurs, and there may be partial submergence of the

continent itself to further enlarge the shelf area. Such is the case along eastern North America.

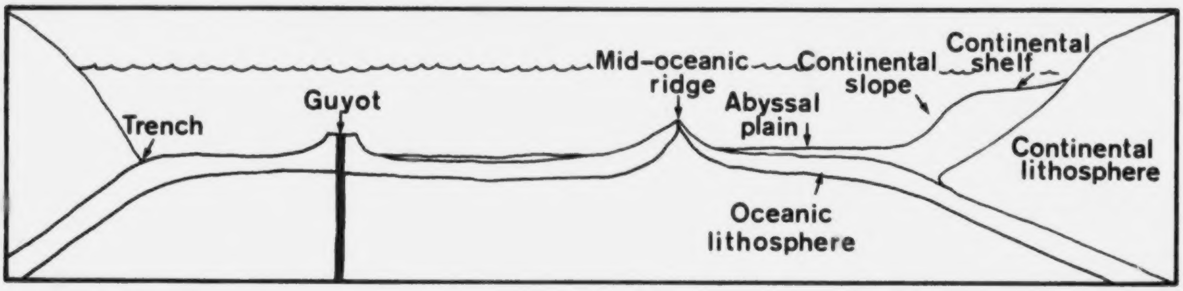


Figure 20.1. In this cross-section of the ocean floor, various features are illustrated.

   b) Continental slope: At the seaward edge of the continental shelf, the slope becomes steeper toward the deep ocean floor. This steeper-sloping area between the continental shelf and ocean floor is the continental slope. (See Figure 20.1) Here, some continental sediment may be deposited. A unique feature of the continental slope is submarine canyons. They are deep valley-like trenches that cut deeply into the slope. Their origin may be from undersea landslides. These landslides consist of water and mud. Because the water and mud are heavier than the surrounding water, they move downslope at high speeds, eroding the canyons as they move. These muddy currents are called turbidity currents.
   c) Continental rise: At a depth of 1,370 to 3,200 meters (4,500 to 10,500 ft), the slope lessens, and a relatively flat surface known as the continental rise may be formed by sediment possibly deposited by the turbidity currents.

2. Deep ocean floor: The deep ocean basin or floor makes up the second major division in the shape of the ocean floor. Most of the deep ocean floor lies below a depth of 4,000 meters (13,120 ft). There are several important features found within this region.
   a) Abyssal plains: These are flat to gently rolling areas created by sediment that covers the ocean floor. They are found off of shores that do not have marginal trenches. The hilly areas are referred to as the abyssal hills (brilliant, huh!)
   b) Mid-oceanic ridges: These high undersea mountains split the major ocean floor into smaller basin areas. Their origins and locations are discussed in further detail in Chapter 9.
   c) Trenches: The deepest ocean depths are found in oceanic trenches which are steep-sided, long depressions in the ocean floor. They are located along some convergent plate boundaries. Their origins and locations are also discussed in Chapter 9.
   d) Seamounts: These are large, isolated submarine mountains of volcanic origin. (See Figure 20.2) Although found in all ocean basins, they are more predominant in the Pacific basin. As with most basin features, their origin is probably related to oceanic plate movement. Their origins are discussed in Chapter 9 under the topic of hot spots.

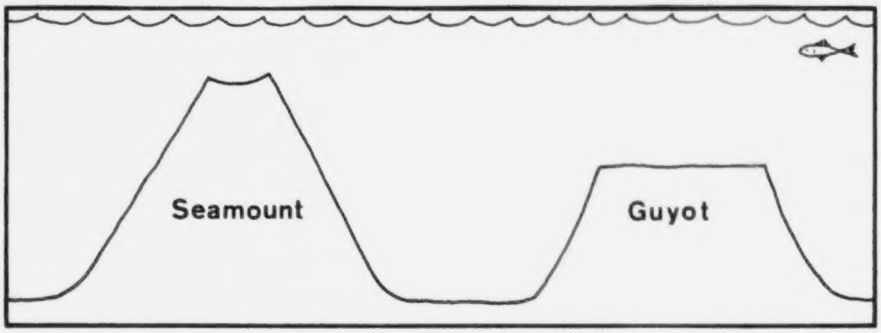


Figure 20.2. Illustrates the change of a seamount into a guyot.

   - e) Guyots (GHEE-ohs): Many seamounts are flat-topped, especially those in the Pacific. These flat-topped seamounts are called guyots and appear to have formed when the seamounts were above sea level. This allowed wave action to erode and flatten the tops. When the sea level rose or the ocean floor subsided, the mountains again became undersea features. (See Figure 20.2)

C. Ocean sediment: As you may have guessed by now, much of the ocean floor is covered with sediment. This sediment is very important because it is the parent material for new mountains, rock layers, and mineral resources.

1. Origin of sediment: Sedimentary materials originate from a variety of sources.
   - a) Land: Sediment from the land (terrigenous) is deposited on the continental shelf and slope through the action of streams, glaciers, coastal erosion, volcanoes, wind, and gravity.
   - b) Ocean: Deep-sea sediment (pelagic) has two sources.
     - (1) Biologic: Material from shells and skeletons of microscopic plants and animals accumulate on the ocean bottom.
     - (2) Volcanic: Submarine volcanoes provide volcanic ash from undersea eruptions.
   - c) Outer space: Meteorites frequently fall to earth and can accumulate. This does not sound like a biggy, but remember, the oceans have been here a long time.
2. Types of sediment: Marine sediment is classified by its composition. The major groups include the following.
   - a) Terrigenous material: This can range from boulder- to clay-sized particles that originated on the land and were then deposited in the ocean.
   - b) Ooze: Beyond the continental shelf, fine-grained sediment is found. If over 30 percent of the sediment is biological material, it is called an ooze. If the ooze has more than 30 percent calcium carbonate (mainly lime), it is called calcareous ooze. If it has a high percentage of silica shells, it is called siliceous ooze.

OOZES
PEGLEG GEORGE'S
OCEANOGRAPHIC STUDIES

c) Red clay: In very deep water, fine sediment exists that does not contain much biologic material and is usually red in color. This sediment forms the red clays. The sediment is so fine that it may take 15,000 to 20,000 years for one centimeter (.39 in) to form on the ocean bottom. All red clays are not red but may be pink or gray.

D. Movement of ocean water: The water of the ocean is always in motion. Wind, gravity, and water density aid in creating this perpetual motion. It has a tremendous effect on our planet, influencing the climate, geologic processes, and life itself. There are three basic types of movement.

1. Currents: Currents are large expanses of ocean water moving in the same direction. They can originate either on or below the surface of the ocean.

a) Subsurface currents: Formed below the ocean's surface, these currents result from a difference in the density of ocean water. As with air, cold heavy water sinks and warm light water rises, so current can be set up as these warm waters move to exchange positions with cold water. As a result, water from polar regions moves toward the equator regions, and water from the equator regions moves toward polar regions. (See Figure 20.3)

b) Surface currents: These currents result from the wind and are affected by the earth's rotation. Thus, in the relationship with the earth's wind systems and rotation, they form circular patterns. (The Coriolis Effect is the force, as a result of the earth's rotation, causing any moving liquid in the Northern Hemisphere to be deflected to the right and in the Southern Hemisphere to the left.) Surface currents are very important in determining the climates of coastal regions around the world.

c) Longshore currents: These currents form along shorelines and will be discussed in more detail later in the chapter.

2. Tides: Tides are the daily rise and fall of the oceans resulting from the gravitational relationship of the earth to the sun and moon. Tides have little effect on geologic processes except in areas where the tidal movement must funnel through narrow openings causing the water velocity to increase greatly. An example of this is the nine meter (30 ft) rise and fall of the water in Bay of Fundy, between New Brunswick and Nova Scotia. (Do not confuse tides with "tidal waves," which incorrectly refer to tsunami.)

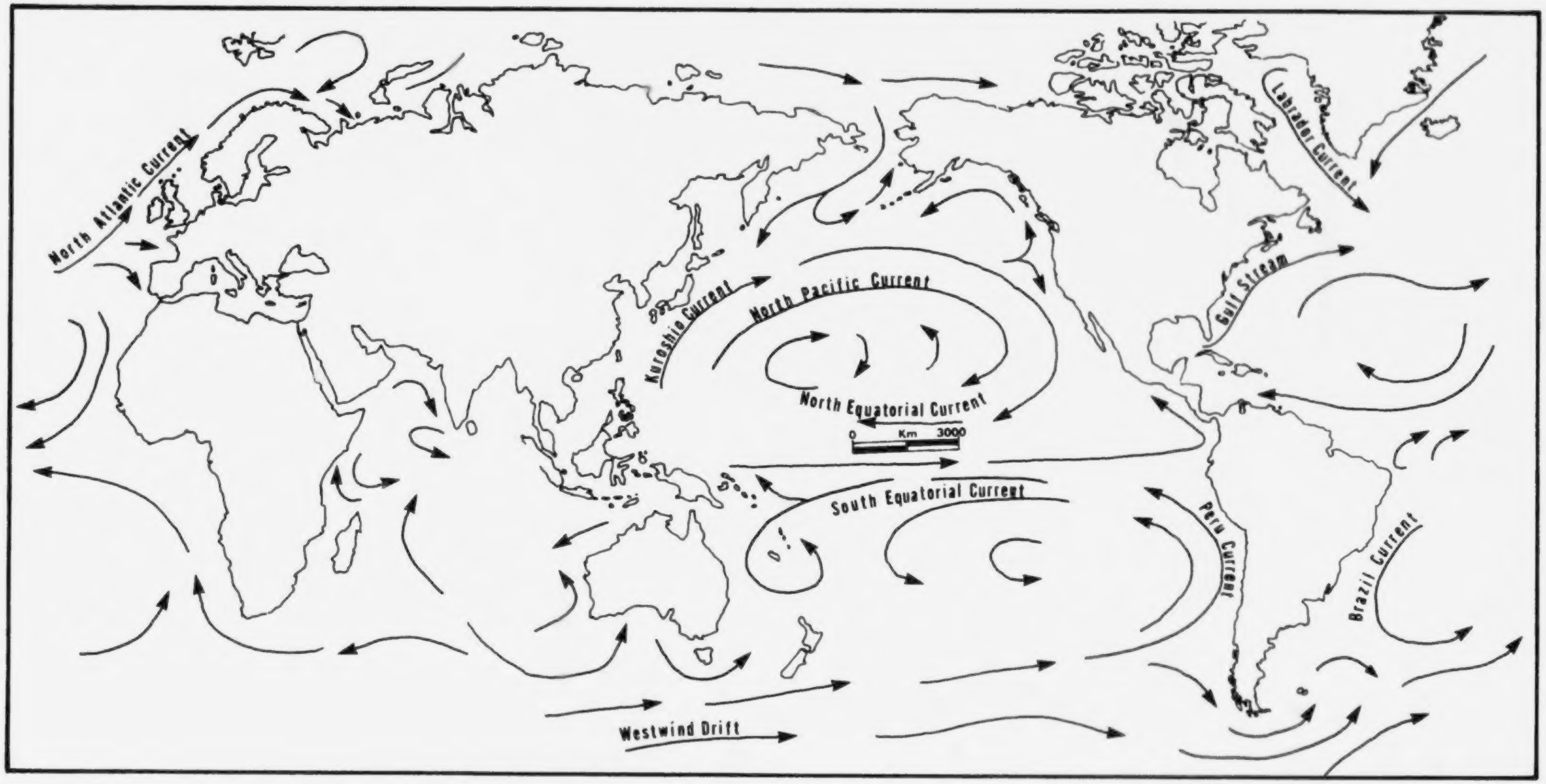

North Atlantic Current
Labrador Current
Gulf Stream
Kuroshio Current
North Pacific Current
North Equatorial Current
0 Km 3000
South Equatorial Current
Peru Current
Brazil Current
Westwind Drift

Figure 20.3. Illustrates the major ocean currents of the earth.

3. Waves: Waves are ridges or swells of water in nearly circular orbits. They are primarily caused by the wind and require a consistent wind direction. Although tsunami and tides are sometimes referred to as waves, we will limit this discussion to wind-formed waves.
   a) Wave structure: Terms have been assigned to various parts of the wave. The top of the wave is called the crest. The depression between two crests is the trough. The vertical distance between the top of a wave crest and the bottom of a trough is the wave height. The distance between two crests is the wave length. (See Figure 20.4) The size of the wave depends upon the speed of the wind, the size of the body of water over which the wind blows, and the extent of time that the wind blows. The greatest wave height measured has been reported to be 30 meters (100 ft).

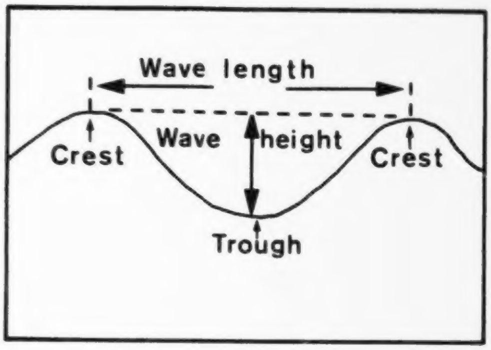


Figure 20.4. Illustrates the various parts of a wave.

   b) Wave motion: The overall motion of waves and that of individual water particles within the wave are very different. In deep water, the wave moves forward with the wind, while the individual water particles move in a circular path to return to nearly the original location. (See Figure 20.5) In shallow water, however, the bottom interferes with the circular motion of water particles. Their energy decreases downward, so that at a depth of one-half the wave length, there ceases to be any movement by the water particles at all.

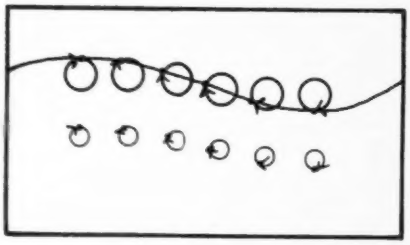


Figure 20.5. Illustrates the motion of an individual water particle in a wave. Notice how the circular motion becomes progressively smaller in deeper water.

   c) Wave refraction: As waves approach the shoreline, they usually are at an angle to the shoreline. But when they reach the shore, they are usually parallel to it. This occurs because, as the waves move into shallow water and encounter the bottom, they slow. If there are parts of the waves that still remain in deeper water, they continue to travel at their original speed. It is because of the different speeds of various parts of the waves that they are bent or refracted to reflect the shape of the shoreline. This process is important to the erosional and depositional pattern of irregular shorelines. The headlands (land jutting out in the ocean) are eroded faster, and the bays (an indention or recess in the shoreline containing ocean water) tend to be areas of deposition.

d) Breakers: As you just read, when waves approach land, they slow. The reason is that when the depth of the ocean bottom is less than one-half the wave length, the water particles in circular motion encounter resistance causing them to slow, crowd together, and steepen. This allows the water on top to move forward, develop a curl on top of the wave, and "break," thus the name breaker. (See Figure 20.6) The area where waves break is called the surf zone. (See Beach Boys' early albums) Here, the water becomes very turbulent and acts as an agent for erosion and deposition. When the waves expend their energy, the water then runs back down the seaward slope of the ocean creating undertow or backwash. The undertow is usually a gentle movement and is not to be feared. However, if the returning water is concentrated in narrow channels, rip currents are created, and these are very dangerous.

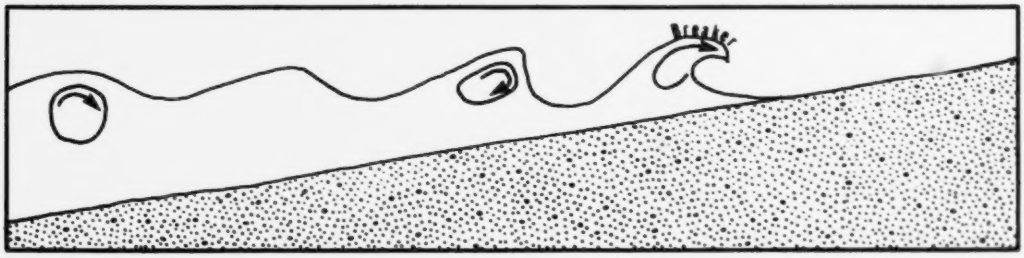


Figure 20.6. Illustrates how wave motion creates breakers. The circles show the motion of water particles.

III. Shoreline development: As with the other external processes you have studied, wave action affects landforms. The effects of wave action again result from agents of erosion, transportation, and deposition. This information applies to large lakes, too.

A. Shoreline erosion: When waves break near the shoreline, they are very turbulent, thus the water becomes an agent of erosion. Even though wave erosion is important in shaping shorelines, the amount of sediment produced is still small compared to that of running water or glaciers.

1. Erosional processes: Shoreline erosion is accomplished by a combination of processes created by wave action.

a) Hydraulic action: This is the pressure or force of water when it is thrown against the shore. The force of waves can move rock and cause rock material to split apart when the force is directed at cracks in the rock surface. During storms, waves have been known to destroy buildings and to toss boulders hundreds of meters inland. The pounding of waves on rocky shorelines can undercut rock material causing rockslides and forming cliffs.

b) Abrasion: This is the grinding of sediment carried by the waves. This process is most active in the surf zone where the sand and pebbles are continually moving back and forth with wave action.

c) Solution: In instances where the shoreline is composed of soluble rock such as limestone, the water may chemically remove the rock through the process of solution.

2. Erosional features: Where the shoreline has exposed rock, the erosion processes are most active, creating a variety of landforms.

a) Sea cliff: As mentioned earlier, when waves attack rocky shorelines, the rock is eroded back, creating a cliff of solid rock called a sea cliff. (See Figure 20.7)

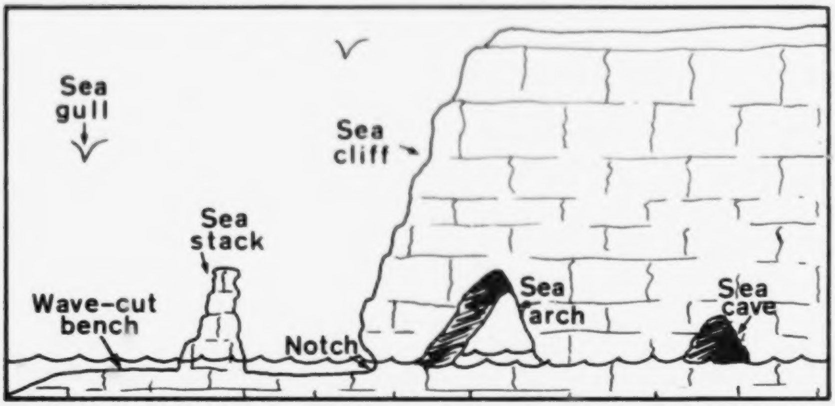


Figure 20.7. Illustrates the various erosional features formed along a shoreline.

b) Wave-cut bench: As a sea cliff erodes away from the ocean, the flat surface of rock just below the water's surface is left as a wave-cut bench or terrace. (See Figure 20.7)

c) Notch: As the waves undercut the bases of sea cliffs, cavities called notches are formed. (See Figure 20.7)

d) Sea cave: In some sea cliffs where the notch is in a zone of weak rock, the pounding surf may enlarge the cavity to produce a sea cave. (See Figure 20.7)

e) Sea arch: If the wave action erodes an opening through a headland, a sea arch is produced. (See Figure 20.7)

f) Sea stack: This is a columnar mass of rock standing alone as an island just beyond the shoreline. It results from an arch eroding away, leaving an isolated rock island. (See Figure 20.7)

3. Duration of erosion: Erosion continues to change shorelines until stability is achieved. In an area of a high shoreline, the predominant process will be erosion. It continues until the wave-cut bench extends to a point where either the wave energy is expended before reaching the sea cliff or the amount of sediment from the land is greater, causing the shoreline to be built seaward.

B. Shoreline transportation: Sediment is transported toward the shoreline as waves break in the surf zone. Since waves usually move toward the shore at an angle, the sediment is moved onto the shore diagonally. However, when the excess receding water and sediment move back down the slope because of gravity, they do so at right angles to the shoreline. The back and forth movement allows the material to be transported down the shoreline. In addition, as the water returns to the ocean, it may meet waves coming in at an angle as longshore currents. They also transport large amounts of sand along a shoreline. (See Figure 20.8)

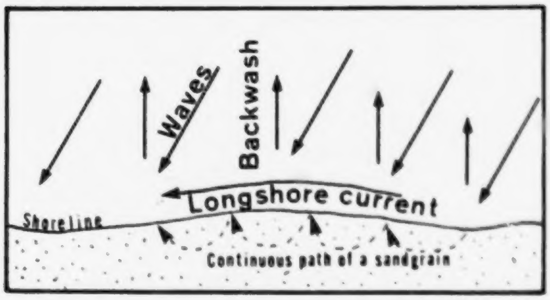


Figure 20.8. An aerial view illustrating the path water follows as it transports sediment to and along the shoreline. Note that it is influenced by wave and current.

C. Shoreline deposition: When the energy of breaking waves and currents is reduced, sediment is deposited. In addition, deposition along the shoreline may occur from the land, contributed by streams, landslides, and sea cliff erosion. Deposition continues until stability is achieved. From deposition several features may form.

1. Beaches: These are the wave-affected areas of the surf zone and are composed of unconsolidated sediment. (See Figure 20.9) The sediment forming beaches comes from both wave erosion and other agents of erosion such as running water. The slope of beaches is controlled by the type of sediment of which they are composed. Therefore, a pebble beach will be steeper than a sandy beach as a result of greater wave energy. As with any sedimentary deposit, the color depends upon the parent material from which the sediment was derived. Even though most beaches are mostly quartz fragments, they may also be composed, for example, of calcite, magnetite, feldspar, and olivine.
2. Sand bars: The sediment that is carried by waves and longshore currents (usually sand) may be deposited on the ocean floor as ridges to form sand bars along the shoreline. The location and type of sand bars are very dependent upon the shoreline shape.
    a) Irregular shorelines: Several features form along irregularly-shaped shorelines. As the longshore currents pass an inlet (a narrow waterway connecting a bay with the ocean), some of the sand forms a ridge extending out from the land into the inlet. These sand bars are called spits. If the spit grows completely across a bay or inlet, it is called a baymouth bar. (See Figure 20.9) If a spit of sand curves at the end, it is known as a hook. (See Figure 20.9) A well known hook is Cape Cod, Massachusetts. A spit that forms to connect two islands or an island to the mainland is known as a tombolo. (See Figure 20.9)

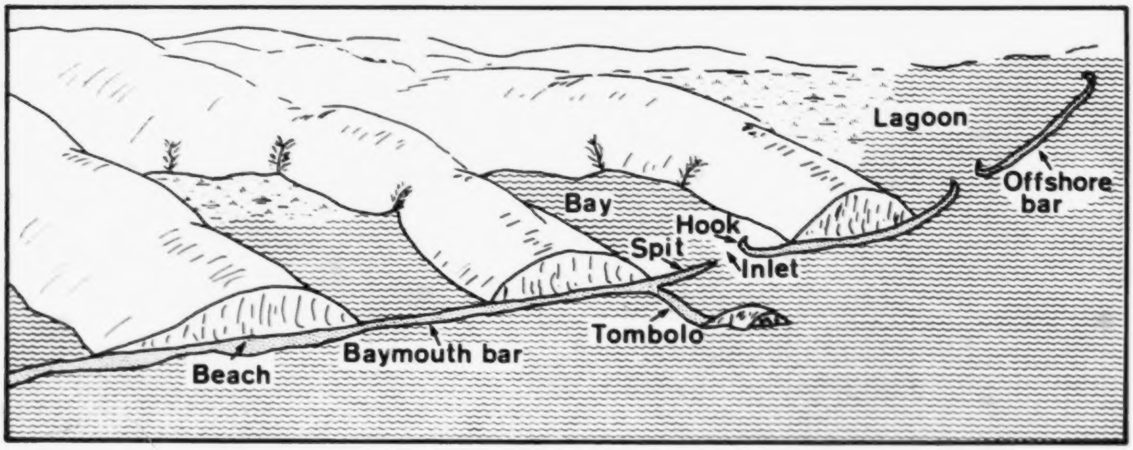


Figure 20.9. Illustrates features formed by shoreline deposition.

b) Regular shorelines: Along relatively straight shorelines, like those found along the Atlantic Coastal Plain, sand bars also form. However, these bars are deposited parallel to but detached from the shoreline in shallow waters and are known as barrier beach or offshore bars. (See Figure 20.9) The famous beaches of Florida are offshore bars. Many of these islands are kilometers long and represent a major hazard for ships along the shorelines. A feature common to both kinds of bars is the lagoon (a shallow body of water that has a restricted connection to the ocean). Lagoons form between sand bars and the mainland, and these are areas protected from strong waves and winds. (See Figure 20.9) As lagoons age, they fill with sediment and may become swampy or marshy.

D. Shoreline evolution: In the case of other external processes discussed in this book, the effects of erosion, transportation, and deposition on the land produce a cycle of changes that continue until an equilibrium is reached. As noted before in this chapter, erosion and deposition continue until they reach a point where the stability of the shoreline is achieved. (See Figure 20.10) However, because of the constant movements of the earth's crust and the effects of other agents, shorelines seldom reach this stability.

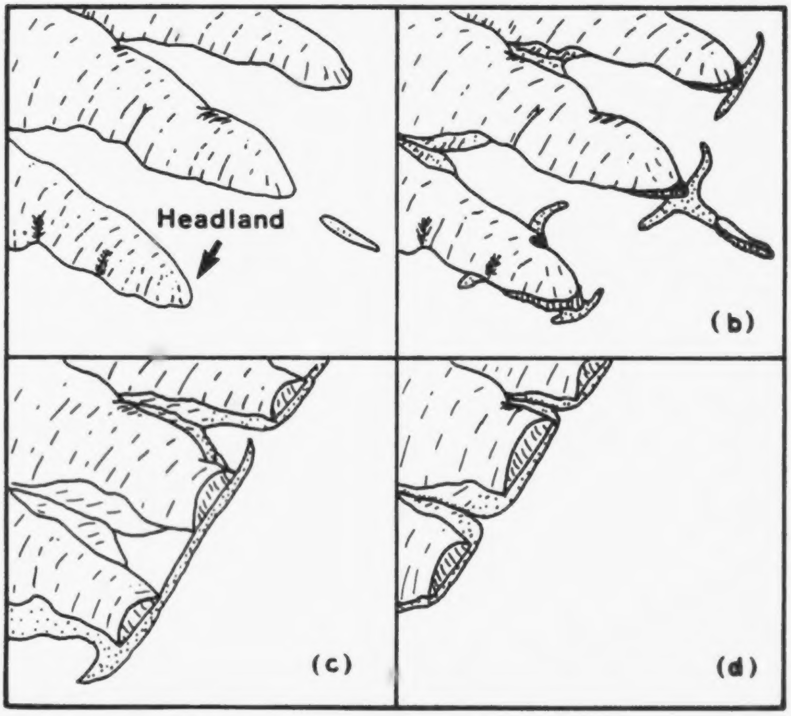


Figure 20.10. Illustrates one possible evolution a shoreline may experience. (a) is the shoreline at the beginning of the cycle. (b) shows erosion of the headland areas and deposition of sediment. (c) is further progression in shoreline evolution. (d) indicates the final stage with headlands and bays nearly eliminated, and the former irregular shoreline now straight.

IV. Classification of shorelines: The classification of shorelines is very complex, and at this time, no one system appears to fit the world's shorelines completely. A major problem is that the recent Pleistocene worldwide rise in sea level has modified all shorelines and caused the reworking of shoreline shapes. But, as with many of the earth's features, a generalized grouping is helpful in understanding landforming processes.

  A. Active shorelines: Active shorelines include those shoreline regions that have either risen or fallen relative to sea level.

    1. Submergent: If the sea level rises or land subsides, many of the earliest shoreline features are covered by water, or submerged. Characteristics of a submergent shoreline include great irregularity, deep estuaries (drowned stream valleys entering the ocean), and isolated islands representing the tops of the upland. Such a situation exists in New England.

    2. Emergent: Rising land or falling sea level resulting in an emergent shoreline will display features such as wave-cut benches and beaches above present water levels. Along the California coast, emergent features are common because of the tectonic activity in the region.

  B. Neutral shorelines: These shorelines have their origins from a source other than change in sea level.

    1. Delta formation: Deltas are found at the mouths of major stream systems draining into the ocean. An outstanding example is the giant Mississippi River delta and the shoreline it has created in the Gulf of Mexico.

    2. Volcanic activity: The shorelines of volcanic islands or locations where lava has flowed into the sea form neutral shorelines.

    3. Coral reefs: In this case, shorelines formed when colonies of small marine animals (corals) built up large deposits in shallow warm seas.

  C. Compound shorelines: Shorelines are complex because many changes affect shoreline development. One shoreline may, within a few hundred kilometers, reflect characteristics of several different types. To solve this problem, the term compound shoreline is used to identify those shorelines with features of more than one type of shoreline.

  D. Other classifications: Two other approaches have been used lately in classifying shoreline development.

    1. Primary/secondary: The primary shoreline has not been modified by action of the ocean. A secondary shoreline is formed by modifying the primary shoreline through external processes.

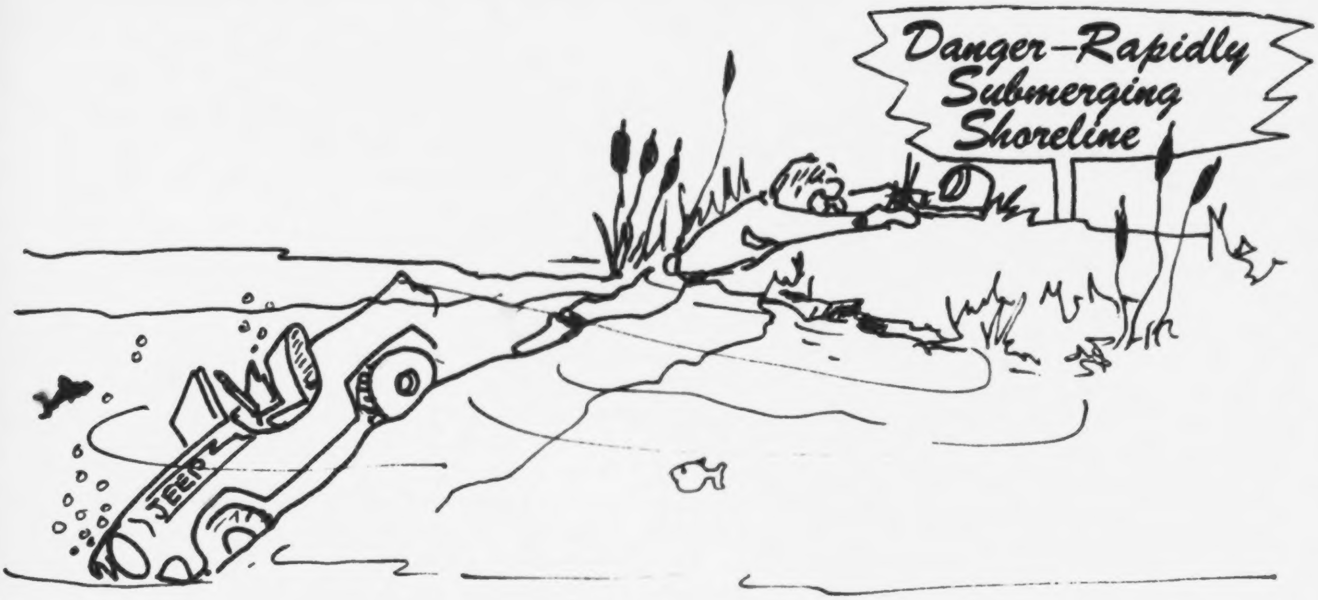
    2. Regular/irregular: As the terms imply, this division is based upon the shape of the shoreline and is similar to the submergent-emergent system.

V. Shorelines and society: The natural processes at work when land and sea meet affect and are affected by people.

  A. Benefits: Shoreline regions of the world offer good harbors for shipping, beaches for recreation, habitat for wildlife and waterfowl, and sources of food.

  B. Hazards: As with many of our natural resources, we do not understand our relationship with the environment, and in efforts to improve, we create more problems. Waves continue to pound against our structures and erode the shoreline upon which homes and businesses are built. Beaches are destroyed by a lack of sand because we dam streams, thereby retaining the land source of sediment. We also destroy beaches by stopping longshore currents. And, of course, pollution flows into streams, is dumped into the ocean, and spreads with the waves and currents.

  C. Solutions: There may not be a "good" solution to some of the shoreline problems. If good harbors are to be kept clear of sediment, some structures must be built to prevent sediment accumulation. Dams may be necessary for flood control and navigation. Other problems exist, though, because we do not realize shorelines are everchanging; therefore, we do not make allowances for those changes when planning for the future.



VI. Summary: Although the size of the ocean is awesome, it is most fortunate for us that its erosive and depositional powers do not compare with its size. Lack of movement certainly is not a reason for its power as an external process. Perhaps for the main purpose of restoring and maintaining balance, the ocean experiences massive vertical and horizontal movements. Of all the movements, it is waves that have the greatest effect in the sculpturing of shorelines throughout the world. The results of their sculpturing provide us with sea cliffs, wave-cut benches, notches, sea caves, sea arches, and sea stacks. The oceans deposit our beaches (delightful vacation spots), sand bars, spits in various sizes and shapes, and offshore bars (and a multitude of topics for songs). All of the above features are created, again, for balance--to achieve an equilibrium between erosion and deposition. However, equilibrium is as difficult as is classification of shorelines because either the land or ocean is always rising or falling, thus "upsetting the applecart." Benefits from shoreline regions are many, but it seems like people are determined to offset the benefits by creating complications in a natural process that, without people, would not have problems. Perhaps it would be more beneficial if we let the ocean "do its own thing" and limit our actions to the reading and writing of fairy tales about the subject.

SEE ACTIVITY 20.1

SEE ACTIVITY 20.2

Chapter 20: Problems and Questions

1. Discuss the importance that oceans have on people, both directly and indirectly.
2. Describe the general features found on the ocean floor.
3. How does the creation of ocean basins relate to plate tectonics?
4. Compare and contrast subsurface and surface ocean currents.
5. What effect does wave refraction have on the shaping of shorelines?
6. Explain briefly the difference in currents, tides, and waves.
7. Explain why a wave "breaks."
8. Describe the various processes of shoreline erosion.
9. Explain how sediment is transported along the shoreline.
10. Compare and contrast sand bar development along irregular shorelines with those along regular shorelines.
11. How do beaches form?
12. Discuss some of the problems geologists have found in trying to classify shorelines into categories.
13. List three (3) problems related to oceans and humanity. Suggest solutions to each problem.

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GEOLOGY IS

Preliminary Edition

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VOLUME II ACTIVITY SHEETS

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ACTIVITY 8.1: Earthquake Waves

Objective: To recognize and demonstrate different types of earthquake waves.

Materials: Slinky, rope, beaker, water, small wood block, small rock, and writing instrument.

Procedure: Follow the instructions below.

1. There are three basic kinds of earthquake waves. List and briefly describe each one.

    a.

    b.

    c.

2. Using the slinky, demonstrate the movement of P-waves. Relate the movement of the slinky to P-waves in the earth.

3. Using a rope, show the movement of S-waves. Relate the movement of the rope to S-waves in the earth.

4. Fill a beaker about three-fourths full of water. Drop in a rock. Describe what happened to the water.

    To demonstrate the destruction caused by L-waves, place a wood cube in water. Drop in a rock. Relate this to earthquake damage. (Remember that the water represents the crust of the earth.)

ACTIVITY 8.2: Earth's Interior

Objective: To draw and label a diagram of the various layers of the earth's interior.

Materials: Text information, circle on next page, ruler, and writing instrument.

Procedure: Using information from your text material, you are to draw a scale model of a cross-section of the earth on the next page. Determine the thickness of each layer on the scale model, and draw corresponding lines to represent that layer. Next, within each layer, list its density, temperature, and composition. Your map is to be neat, and all information must be printed.

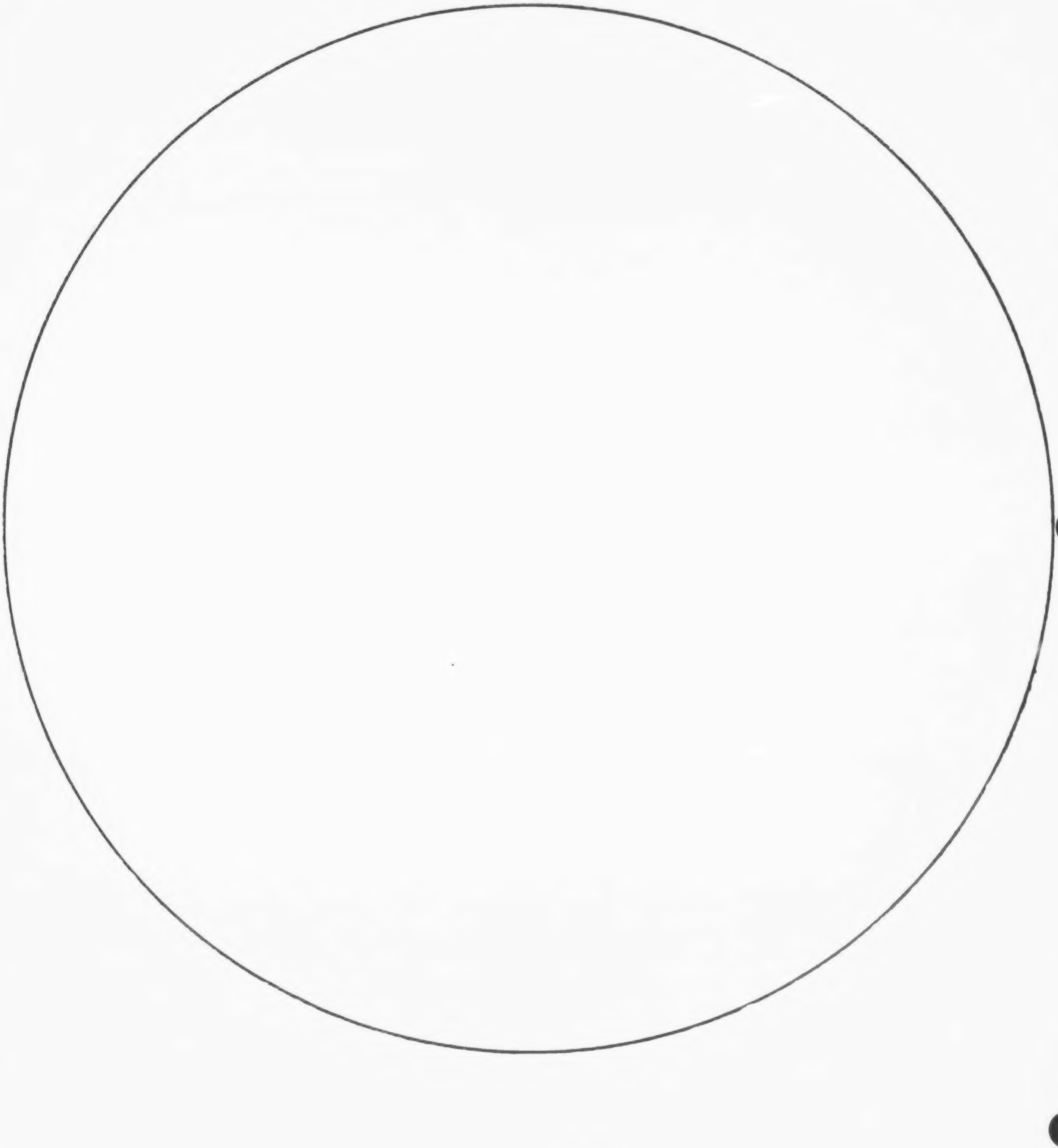
HINT: The diagram of the earth is 12,800 km. The scale of the map on the next page is 2.54 cm. = 1,600 km.

CONVERSION FACTORS

1 inch = 2.54 centimeters
1,000 miles = 1,600 kilometers

(over)

ACTIVITY 8.2: Earth's Interior (continued)



ACTIVITY 9.1: The Geography of Plate Tectonics

Objectives: To locate features associated with the various types of crustal plate boundaries.
To relate tectonic features to specific plate locations.

Materials: National Geographic Society maps: Atlantic Ocean Floor and Pacific Ocean Floor, text.

Procedure: Using the ocean floor maps(the physical relief side) answer the following questions.

Atlantic Ocean Floor Map:

1. What are the most noticeable ocean floor features on this map?

Explain the origin of these features.

2. Notice that Iceland (northern part of the map) lies over the spreading ridge. What can you conclude about the origin and composition of the island?

3. The Atlantic Ridge is composed of a series of fractures at right angles to the ridge(s). Explain their origin and their name.

4. The Azores (west of the Iberian Peninsula-Spain and Portugal to non Iberians) is about 20 million years old while the Canary Islands(just west of northwest Africa) is about 90 million years old. Account for the differences in their ages.

(over)

ACTIVITY 9:1: The Geography of Plate Tectonics (continued)

5. Notice that the edges of the Atlantic Ocean basin have shallow areas near the continental coasts. Can you explain the cause of these shallow areas? Say yes and explain why the areas exist.

6. Look at the west coast of Central and South America, very little continental shelf exists. Why?

7. What type of plate boundary occurs along these coastlines?

8. What kind of continental features are found adjacent to these zones?

   Explain how the features form.

9. On the east side of the map, near the equator, (in Africa) is the Great Rift Valley. Based on its name and your in-depth knowledge of plate tectonics, discuss what this area may represent.

Pacific Ocean Floor map:

1. Using this map,you can see the cause of the subduction of the ocean floor at Central and South America. Explain that cause.

ACTIVITY 9:1: The Geography of Plate Tectonics (continued)

2. In general, how does the sea floor appearance differ in the east Pacific from that of the west Pacific?

3. Looking at the ocean floor features in the western Pacific suggest possible origins of such island groups as the Philippines, Japanese Islands and the Aleutians. Please explain in detail! (more than one word)

4. How do these features differ from those associated with subduction zones near continents?

5. Based on the location of the trenches and rift zones in the Pacific, which way (or ways) is the Pacific Ocean floor moving?

   Explain your answer.

6. In summary, explain the relationship of subduction zones and rift zones with eartquakes and volcanoes.

Chapter 9

ACTIVITY 9.2: Puzzle

Objective: To work a puzzle using plate tectonics vocabulary terms.

Materials: Writing instrument and puzzle below.

Procedure: Identify the terms described below, then locate them in the puzzle. They may be frontward, backward, horizontal, vertical, or diagonal.

L	O	L	I	T	H	O	S	P	H	E	R	E
I	T	N	E	G	R	E	V	I	D	O	S	D
N	N	H	R	B	O	M	O	D	E	G	N	S
C	E	T	H	I	M	A	L	A	Y	A	S	U
O	G	I	J	K	O	N	C	I	L	M	Q	U
N	R	I	F	T	P	R	A	A	E	E	P	A
V	E	R	I	D	G	E	N	B	T	R	A	L
E	V	C	A	L	I	A	O	P	A	I	N	A
C	N	U	V	Y	W	S	A	X	L	C	G	T
T	O	C	I	D	A	P	I	L	P	A	A	E
I	C	O	N	T	R	E	N	C	H	N	E	R
O	G	O	C	I	N	O	T	C	E	T	A	A
N	G	S	U	B	D	U	C	T	I	O	N	L

1. The sideways horizontal movement that occurs along some plate boundaries.
2. The name of the plate upon which we are traveling.
3. In a zone of subduction, these creations are produced from the rising of hot magma.
4. In this zone, a heavy oceanic plate meets a lighter continental plate and dives under.
5. This describes a plate boundary in which the plates come together.
6. The name of the supercontinent in which all land was joined into one big hunk.
7. The name of the once single continent in the Southern Hemisphere.
8. The deformation of earth materials on a large scale.
9. A large chunk of the lithosphere.
10. A rather narrow rise that has steep sides.
11. A deep valley caused by a break in the lithosphere, following along the crest of the mid-oceanic ridge.
12. A long, narrow depression formed in the zone of subduction.
13. A type of plate boundary in which two plates move away from each other.
14. A large mountain range in Asia, formed when two plates crrrrrunched into each other.
15. The crust plus some upper mantle.
16. The mass movement of mantle material caused by heat flow.

ACTIVITY 10.1: Earthquakes and People: Planning for the Future

Objectives: To review potential earthquake hazards.
To suggest possible ways that those hazards can be minimized.

Materials: Text, some thought(not too much,it may be painful) and some good ideas.

Procedure: Follow the instructions for each section.

Part I: Earth Materials

Based on your knowledge of earth materials and how earthquakes affect the material, discuss the behavior of the following during an earthquake.

Solid bedrock:

Sediment:

What effect would slope have on the above materials?

Would moisture in the material make any difference in the amount of movement?

Explain your answer.

Part II: Geographic Location

Describe problems that might be associated with specific geographic locationa should an earthquake occur.

1. river floodplains, lowlands:

2. mountainous regions:

3. flat,bedrock surfaces:

(over)

ACTIVITY 10.1: Earthquakes and People (continued)

Part II: Geographic Locations (continued)

4. ocean shorelines:

5. canyons/valleys:

Part III: Effects on Structures

Describe the effects an earthquake might have on the following structures. Also explain how the effect might be lessened.

1. bridges:

2. tall buildings:

3. highways:

4. pipelines:

5. canals:

6. homes:

7. power plants:

8. dams:

Chapter 10

ACTIVITY 10.1: Earthquakes and People (continued)

Part IV. Prediction,Preparation and Planning

In this section, discuss how earthquakes predicted and what a community, county or state could to to minimize the effect of an earthquake .

A. List the kinds of scientific information needed to predict the possibility of an earthquake.

B. Make a list of steps (a plan) that a community, county, or state could make to keep damage and injuries to a minimium should an earthquake occur. HINT: look at your other three sections in this activity.

ACTIVITY 11.1: Volcanic Features on the Earths' Surface

Objective: To identify various volcanic landforms and features as seen of topographic maps.
To review the possible origins of these features.

Materials: 100 Topographic Maps book, location grid, and text.

Procedure: After answering the review questions use the 100 Map book to answer the rest of the questions.

1. Review Questions:

   a. Name and describe the three basic types of volcanic cones.

   b. Briefly describe the erosion cycle of a volcanic cone.

2. Page 33- Menan Buttes, Idaho
   The feature at D2 is a cinder cone. List several characteristics you see that would confirm this.

   This a relatively young cone. Explain how you could tell this from the map.

   What kind of material would you expect to to be found at A,1-5 and B,1-2.

   Explain your reasoning (or guess).

(over)

ACTIVITY 11.1: Volcanic Features (contined)

3. Page 78-Chemult, Oregon
   Compare Odell Butte with Black Rock Butte (A,2). Both are volcanic cones. How are their shapes different?

   What has caused this difference to occur?

4. Page 79- Crater Lake, Oregon
   Crater Lake is a caldera. Briefly describe how such features are formed.

   Based on what is left of the volcano, what kind of a cone do you think it was(is).

   Give your reasons.

   Wizard Island (C,2) is a volcanic cone formed after the caldera was created. What kind of cone is it. There are two correct answers.

   Pumice is probably one of the igneous rocks found on this area. How did we arrive at that conclusion?

ACTIVITY 11:1 Volcanic Features (continued)

5. Page 65- Shiprock, New Mexico
   Explain what the feature known as Shiprock is.

   What stage of the volcanic cone erosion cycle is Shiprock in?

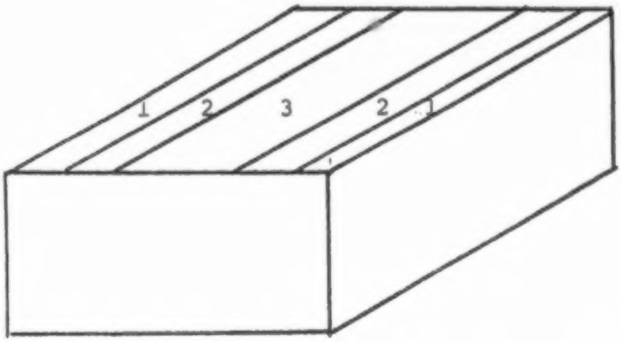
   Explain the general geologic history of this region from its creation to the present appearance.

ACTIVITY 12.1 Determining the Shape of Folded Structures

Objectives: To use surface rock patterns and relative age relationships of folded rocks to determine their structure.
To draw cross sections of these folded structures.

Materials: Text, some imagination and a pencil (then you can erase mistakes before I see them).

Procedure: Using the information given on the block diagrams as to pattern and relative ages, draw the front and sides (if necessary). Then name the kind of fold. NOTE: The oldest rock unit is #1.



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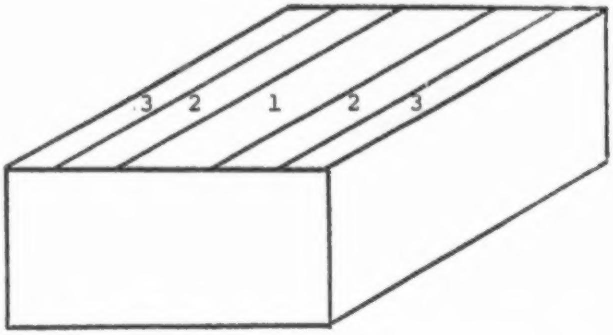

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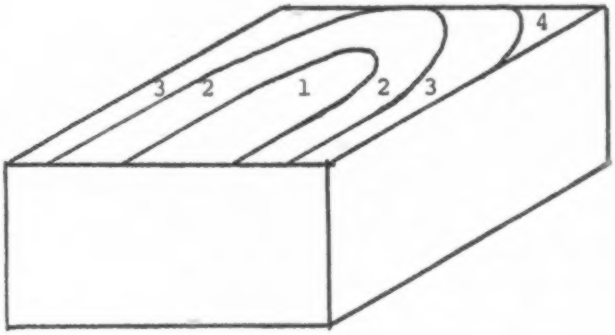

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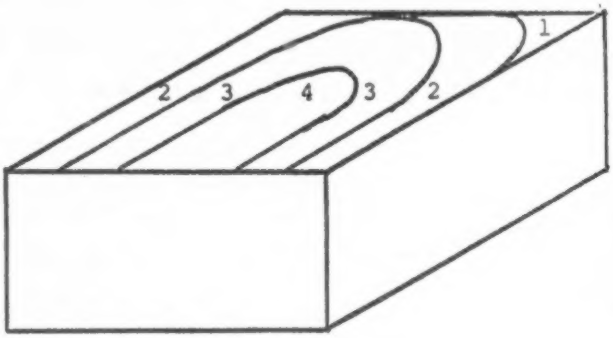

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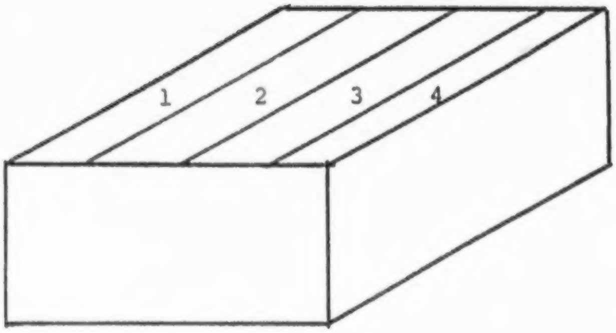
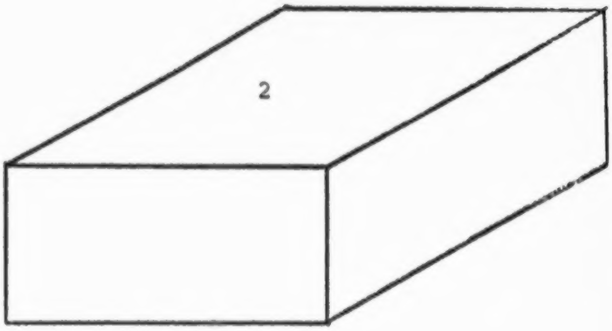
ACTIVITY 12:1 Folded Structures (continued)



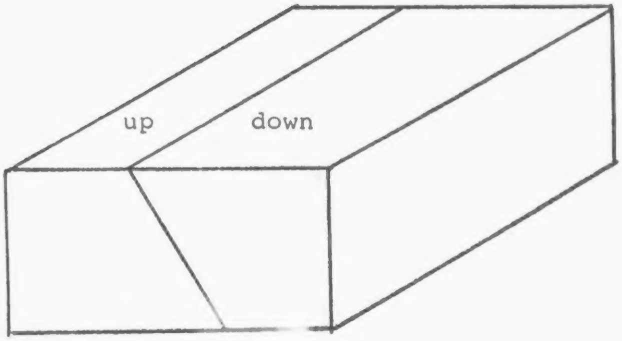


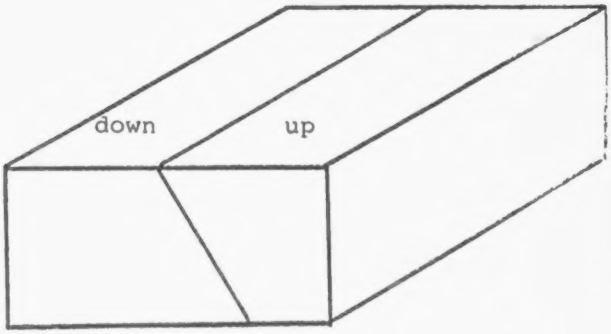
ACTIVITY 12.2 Determining Basic Fault Types

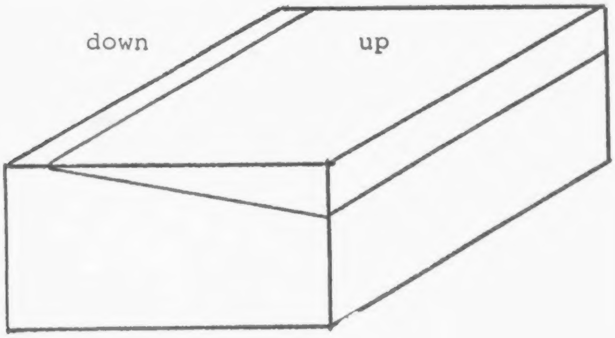
Objective: To use footwall, hanging wall relationships and fault angle to determine basic fault types.

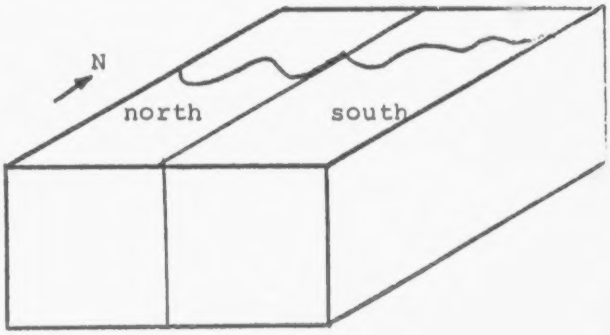
Materials: Text, box of hanging walls and footwalls, a few arrows, a knowledge of faults(oh well, 3 out of 4 isn't bad).

Procedure: Using the information as to which side of the fault moved and which way it moved, draw the proper arrow directions and label the footwall & hanging wall. Then name the type of fault.









ACTIVITY 12:3 Structural Deformation of the Earths' Surface or Bent and Broken Rocks and How They Look

Objectives: To identify and interpret evidence of crustal movement.
To relate geological structures to mountain building processes.

Materials: 100 Topographic Maps book, location grid and text.

Procedure: Using the 100 Map book, answer the questions in the following activity.

Folded Structures:

1. Page 83- Tyrone, Pennsylvania
The features known as Brush Mountain, Canoe Creek and Canoe Mountain are part of the same fold. By looking at the shape of the feature, name the kind of fold it is.

   The explanation at the bottom of the page notes that the structure is a synclinal valley and mountain. In the space below, sketch a cross section of the structure. Also label the geographic names of the parts of the fold.

2. Page 100- Strasburg, Virginia
The Strasburg region is folded. List the features and patterns that are evidence of folding.

   Looking at the map, do you see any problems these folded mountains could have caused early settlers and travelers? Answer yes like you are supposed to and explain the problems.

(over)

ACTIVITY 12.3: Structural Deformation (continued)

Domes and Basins:

3. Page 32- Warm Springs, Georgia
   How was the feature known as The Cove (A,3-4;B,3-4) formed?

   Based on your description, sketch a cross section of the Cove area showing the rock structure at grid line B. Name the geographic features that are crossed.

4. Page 108- Maverick Springs, Wyoming
   This map includes parts of two domes; a large dome covering the northern part of the map and a smaller one in the south-eastern corner. With only what is shown, can you prove they are domes?

   Why or why not?

   The large dome has several stream valleys around its flanks (sides). How did these valleys form in this shape?

ACTIVITY 12:3 Structural Deformation (continued)

Faults and Fault Blocks:

Evidence of faulting is often difficult to see on topographic maps and on aerial photographs. Explain why.

5. Page 78- Chemult, Oregon
   Cresent Butte (A,5), a volcanic cone has been faulted. How is the fault shown on the contour map?

   Sketch a cross section of Crescent Butte and label the fault scarp.

6. Page 13- Bright Angel, Arizona
   Bright Angel Canyon (C4,B4-5) is a fault valley. Why would a fault line be a logical location for a major stream valley?

Volcanic Structures:

7. Page 33- Menan Butte, Idaho
   As a review, describe the cone at D2 on this map. In other words, how can you tell this is a volcano?

Chapter 12

ACTIVITY 12.4: Mountains: Where and Why

Objectives: To locate some of the major mountain ranges of the world.
To list the possible origins of these major ranges.

Materials: World outline map, atlas, red, blue and black pens or pencils, ruler.

Procedure: Using the atlas (or your own great geographic knowledge), locate the mountain ranges listed below. Shade each range area on the map in red and print the name in black. Next, draw the major plate boundaries on the map in blue. These boundaries can be found on the map in Chapter 9. Upon completion of drawing the boundaries, label the plates by name. PRINT! Finally, fill out the chart below.

Part I: Mountain ranges to be located.

Alps
Andes
Appalachians
Atlas
Cascades
Himalayas
Rockies
Sierra Nevadas
Urals

Part II: Data on the mountain ranges.
Note: Remember the ruler listed in the materials? Guess who gets to make the chart as well as fill it out? You do!

The headings for your chart are:
Range Name
Location (Continent)
Type of Mountains
Origin

Use the back of this sheet for your chart. Be sure to allow enough space for the necessary information and PRINT it neatly. Yes, I know neatness causes a rash on teenage bodies, but that's the breaks.

Chapter 13

ACTIVITY 13.1: Plains and Plateaus on the Earths' Surface

Objectives: To recognize characteristics common to plains and plateaus as seen on topographic maps.
To review the processes that create and modify plains and plateaus.

Materials: 100 Topographic Map book, location grid and text.

Procedure: Using the 100 Map book,answer the questions below.

1. Review Questions:
   a. Explain the difference in a plain and a plateau.

   b. Name the types of plains.

   c. Name the types of plateaus.

2.Page 11- Mobile, Alabama
What kind of plain is shown?

Explain its origin.

3.Page 35 Effingham, Illinois
What type of plain is this region? (see pages 111-115 in topo. book, if unsure)

Describe how it looks different for the Mobile, Alabama region.

Why do you think this area is so much more dissected (big word that means hilly) than the Mobile,Alabama region?

(over)

Chapter 13

ACTIVITY 13.1: Plains and Plateaus

4.Page 38- Lake McBride, Kansas
Even this area is highly dissected (eroded), you can still see evidence that the area is a plain. Describe the evidence.

Plateaus:

5. Page 13- Bright Angel, Arizona
As noted, this is a dissected plateau. Compare this area to the Effingham,Illinois area (p.35) and explain how the regions differ and why. Neat question,Huh.

6. Page 15- St. Paul, Arkansas
This region is a very old, dissected plateau. What evidence do you see on the map that the area is a plateau.

7. Page 34- Thousand Springs, Idaho
What kind of plateau is this?

There are several features on the map that can be used as evidence in determining the type of plateau. Name two.

ACTIVITY 13.1: Plains and Plateaus (cotinued)

7. (continued)
Draw a cross section, with major elevations given and any named features labeled, from east to west at the #s 28,29 and 30(north part of map). Explain how the profile can help show that the region is a plateau.

8. Page 36- Oolitic, Indiana
Southern Indiana is part of the "low plateaus". Originally a plain, the region has been slowly uplifted. What features on the map shows this uplift?

ACTIVITY 14.1: Observing Chemical and Physical Weathering or the pothole and rust fieldtrip.

Objective: To observe and record examples of the various kinds of weathering processes in a local setting.

Materials: Clipboard or other hard surface for writing on, keen observation senses(or luck), text.

Procedure: In this activity, you will take a mini- fieldtrip. Your instructor will take you on a tour of the school campus. The purpose of this tour is for you to locate and describe examples of both physical and chemical weathering.

Each example should include the following information:

1. Type of Weathering; physical or chemical or both.
2. Specific kind of physical or chemical weathering.
3. A description of what is occurring. Include both the probable cause, the result and possible problems that may be caused by the weathering.

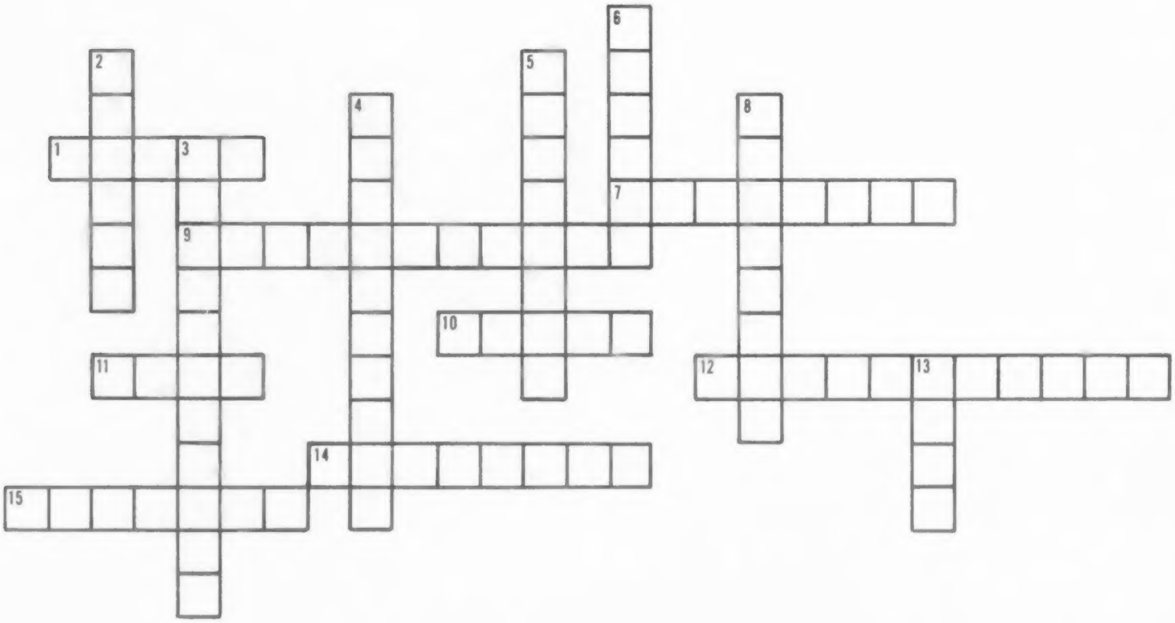
NOTE: Your instructor will determine the number of examples you should have.

ACTIVITY 14.2: Puzzle

Objective: To work a puzzle using weathering terms.

Materials: Writing instrument.

Procedure: Read the definitions below, determine the terms being defined, and use the terms to work the puzzle.



ACROSS

1 The necessary compound needed in most chemical weathering.
7 ____________ processes--activities that take place on or near the surface of the earth.
9 The breaking up of rock caused by water freezing in the cracks of rock. (2 words)
10 Feldspar plus water give __________ and sand. (plural)
11 The most important product of weathering.
12 The pulling downward of rock fragments by gravity. (2 words)
14 ____________ processes--activities that begin down inside the earth.
15 The removing of broken-up rock.

(Turn page for DOWN terms)

ACTIVITY 14.2: Puzzle (continued)

DOWN

2 A mineral that is very resistant to weathering.
3 The peeling off of outside layers of rock.
4 The breakdown of rocks and minerals.
5 The kind of weathering in which nothing is changed except the size of the rock.
6 ___________ plus iron give rust.
8 The kind of weathering which results in a change in a rock's composition.
13 Carbon dioxide plus water give ___________.

ACTIVITY 15.1: Mass Wasting Processes

Objective: To review and organize information about the various forms of mass wasting and the conditions necessary for each.

Materials: Text, ruler (guess why!) organized thought processes (if possible)and 11x14 sheet of paper.

Procedure: Draw a chart, divided into the headings listed below. List each kind of mass wasting on the chart,then fill out the information under each heading for each kind of mass wasting.
The chart should be neat and the information printed. Don't forget a title and your name.

Kinds of Mass Weathering:

Soil Creep
Solifluction
Earthflow
Mudflow

Slump
Debris Slide
Rock Slide
Rockfall

Information Headings:

Earth Material
Speed of Movement
Slope Steepness
Climatic Conditions (moisture,temperature, etc.)
Special Conditions
Prevention/Controls (if any)

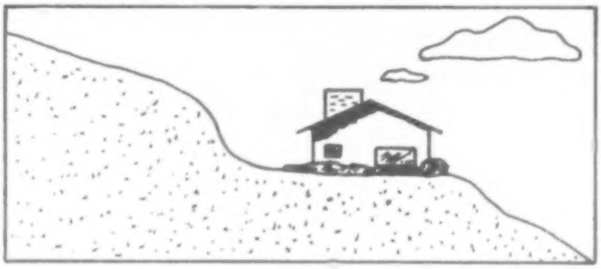
ACTIVITY 15.2: Mass-wasting Problems

Objective: To identify building problems related to mass-wasting, and to find solutions to these problems.

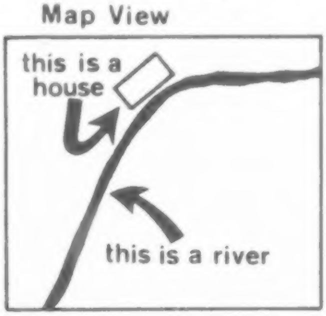
Materials: Critical thinking, situations below, and writing instrument.

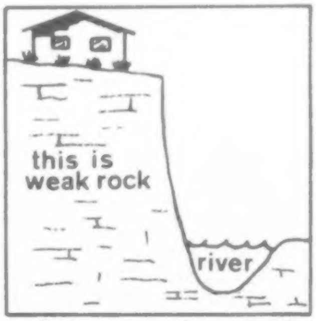
Procedure: You are a famous geologist who specializes in mass-wasting. Below are various problem situations on which you will give advice. Answer any questions asked. P.S. You will not receive a fee because your generous nature prompted you to volunteer for these jobs, but you may claim your expenses on income tax.

1. Mr. and Mrs. John Doe are going to build their dream house. They have chosen a location on the side of a hill. Part of the hill, which is presently covered with vegetation, will have to be leveled to support the house. The diagram below illustrates the final product. Anticipate problems that may occur with this hillside construction, and provide possible solutions.



2. Look at the map view and cross-section of the home site below. Would you advise that a house be built at the indicated location? Why?





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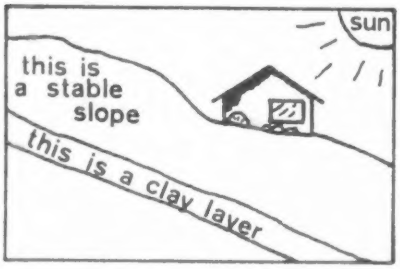
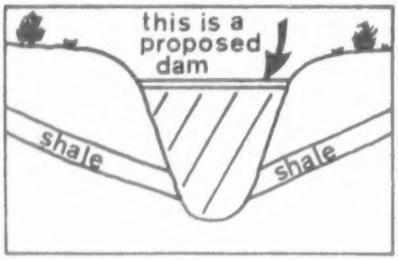
ACTIVITY 15.2: Mass-wasting Problems (continued)

3. The location of this house provides a lovely view of the countryside. This is in an area of heavy spring rains. What is your expert opinion?

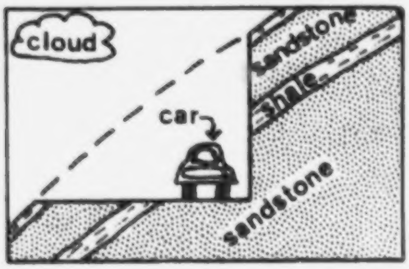

sun
this is a stable slope
this is a clay layer

4. This is the location of an area with a restricted water supply. The proposed dam would increase the water supply and provide a much-needed recreation area. Should the dam be built? What do you suggest?

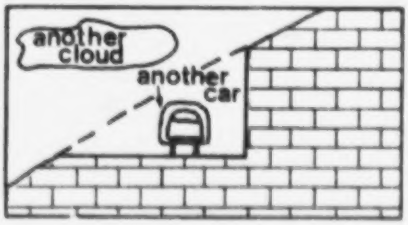

this is a proposed dam
shale
shale

ACTIVITY 15.2: Mass-wasting Problems (continued)

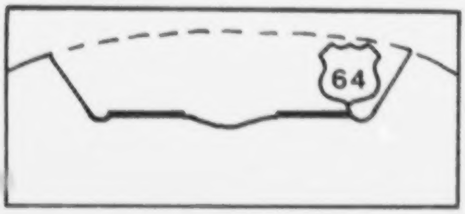
5. It is necessary to build a highway along a hillside. Look at the cross-section, and give your advice on how you might control mass-wasting.


cloud
car
sandstone
shale
sandstone

6. This is a roadcut in a stable limestone. Is a retaining wall needed along the side of the road? Why?


another cloud
another car

7. The slopes along I-64 are composed of soils, for the most part. How should the slopes be treated to prevent mass-wasting?



ACTIVITY 16.1: Porosity and Permeability

Objectives: To determine the porosity and permeability of some common rocks.
To relate this information to the movement of ground water through these rocks.

Materials: A variety of rocks selected by your instructor, container for water, water and a triple beam balance.

Procedure: First, answer the review questions. Then follow the instruction is part II to determine the permeability and porosity of the various rocks. Finally write up the results and answer the questions.

Part I: Review Questions:

a. Define porosity and permeability.

b. Explain why porosity and permeability are important to the movement of groundwater.

Part II: Porosity and Peameability Testing:

1. Make a chart listing all of your rock samples by name. Then divide the horizontal part of the chart into the following columns; dry weight, wet weight, difference in weight and percent of change.
2. Weigh each rock sample and record the weight in the proper column.
3. Place the rock samples in a container of water, making sure that the samples are completely covered.
4. After 48 hours, remove the samples and weigh them again.Record this information on your chart. Now find the weight differences (if any) and determine the percentage of change. Oh no,not math!
5. Complete the information needed in the next section and answer the questions.

(over)

ACTIVITY 16:1. Porosity and Permeability (continued)

Part III: Results:

1. Which rock samples showed;

   The greatest change-

   Minor changes-

   Little or no change-

2. Account for these differences, be specific. In other words, explain why changes occurred in each rock sample(or didn't occur).

3. Which of the rock types would make the best aquifers?

4. Which would make the poorest aquifers?

5. By the way, what is an aquifer?

ACTIVITY 16:2. Groundwater Related Features on the Surface

Objectives: To identify surface features associated with groundwater related features.
To relate some of those features to environmental problems.

Materials: 100 Topographic Map book, location grid, text and a little book learning about groundwater stuff.

Procedure: Based on information you see and read about in the 100 Map book, answer the following questions.

Part I: Springs and Wells

1. Page 34- Thousand Springs, Idaho
From the information given about this region, what kind of rock material do you think the springs along the Snake River are formed in?

   Why?

2. Page 41- Mammoth Cave, Kentucky
Several springs are found on the map. Name two.

   What is the origin of these springs?

3. Page 59- Ashby, Nebraska
A large number of "flowing wells" are located in this region. What is another name for a flowing well?

   Why do these wells flow? Don't just name a process, explain it!

(over)

ACTIVITY 16:2. Groundwater Features (continued)

Part II: Swamps and Lakes

Explain the origin of the swamps and lakes of the following maps. By the way, what is the difference in a lake and a swamp?

swamps,marshes,bogs etc.
1. Page 11- Mobile, Alabama

2. Page 21- San Luis Rey, California (B,3)

3. Page 31- Lake Wales, Florida (A,2)

4. Page 42- Campti, Louisiana (B,5)

5. Page 49- Provincetown, Massacusetts (D,1&2)

lakes and ponds
6. Page 17- Bray, California (D,1)

7. Page 24- Commerce City, Colorado (length of the South Platte River floodplain)

8. Page 31- Lake Wales, Florida (any and all)

(over)

ACTIVITY 16:2. Groundwater Features

9. Page 42- Campti, Louisiana (D,1&2)

10. Page 57- Chief Mountain, Montana (any and all)

11. Page 79- Crater Lake, Oregon

12. Page 81- Altoona, Pennsylvania (E2)

Part III- Caves and Karst

1. Page 31- Lake Wales, Florida
   List two reasons that you think this region has underground drainage.
   a.

   b.

   What kind of rock probably underlies this area?

   Explain how you arrived at that conclusion. Guessing and looking at someone else's answer don't count!

   Do you think there are many open cave passages beneath this area?

   Why or why not?

ACTIVITY 16:2. Groundwater Features (continued)

Part III: 1. (continued)

List two environmental problems that could occur in this in this area.
a.

b.

2. Page 36- Oolitic, Indiana
What is the most noticeable karst feature on this map?

Oh, almost forgot; what is a karst feature?

How are these features shown on the map?

Notice that very few sinkholes in this area contain water. Explain the probable reason for this.

There are more likely to be explorable cave passages in this region than in the Lake Wales, Florida area. Explain why.

What role has the White River played in the development of this karst area?

The west side to the map does not have many sinkholes. Explain the probable reason.

There are several quarries located in the northeast part of the map. What kind of rock do you think they are quarrying?

Explain how you reached the above conclusion(or guess).

ACTIVITY 17.1: Running Water Charts

Objective: To review running water processes and products.

Materials: Writing instrument and Chapter 17 information (or remarkable recall).

Procedure: Fill in the following charts with the necessary information. (They will further aid you in your chapter review.)

1. Fill in the chart below describing the processes that accomplish stream erosion.

NAME	SOURCE OF WATER	LOCATION IN RELATION TO STREAM	PROCESSES INVOLVED	VARIABLES
SHEET EROSION				
HEADWARD EROSION				
ABRASION				
SOLUTION				
HYDRAULIC ACTION				

(over)

ACTIVITY 17.1: Running Water Charts (continued)

2. Fill in the chart of depositional features.

NAME	SIZE OF SEDIMENT	LOCATION(S) OF DEPOSIT	DISTINCTIVE SHAPE
FLOODPLAIN			
SEDIMENT BAR			
NATURAL LEVEE			
SLIPOFF SLOPE			
BACKSWAMP			
ALLUVIAL FAN			
DELTA			

ACTIVITY 17.1: Running Water Charts (continued)

3. Fill in the chart describing stream valley development.

PROCESS	HOW THE PROCESS IS ACCOMPLISHED
VALLEY DEEPENING	
VALLEY WIDENING	
VALLEY LENGTHENING	

(over)

ACTIVITY 17.1: Running Water Charts (continued)

4. Fill in the chart describing different types of drainage patterns.

NAME OF DRAINAGE PATTERN	CAUSES	EXAMPLES
DERANGED		
DENDRITIC		
TRELLIS		
RECTANGULAR		
RADIAL		
PARALLEL		
ANNULAR		

ACTIVITY 17.1: Running Water Charts (continued)

5. Fill in the chart comparing the three stages of stream valley development.

	INITIAL DEVELOPMENT	INTERMEDIATE DEVELOPMENT	FINAL DEVELOPMENT
AMOUNT OF DOWNCUTTING ACTIVITY			
AMOUNT OF LATERAL CUTTING			
GRADIENT			
UPLAND AND VALLEY SHAPE			
NUMBER OF TRIBUTARIES			
SHAPE OF THE STREAM'S PATH			
DRAINAGE OF UPLAND AREAS			
FEATURES IN STREAM CHANNEL AND/OR FLOODPLAIN			
TYPE AND/OR AMOUNT OF SEDIMENT CARRIED			
IS EROSION OR DEPOSITION DOMINANT?			

ACTIVITY 17.2: Stream and Stream Related Features on Topographic Maps

Objectives: To identify and interpret stream related features.
To relate running water processes to landform development.
To explain the effects of streams on people.

Materials: 100 Topographic Maps book, location grid and text or Act. 17.1.

Procedure: Using the 100 Map book, locate the maps necessary and answer the following questions. Note that the topics follow the chapter outline(kinda!).

I. Sources of Water
What is the major source of surface water?

Page 34- Thousand Springs, Idaho
Name a source of water for the Snake River shown on the map.

Page 38- Lake McBride,Kansas
Name the major source of water for Lake McBride.

Page 104- Mount Rainier,Washington
What, in addition to rainfall, is the major source of water for the streams on the slopes of Mount Rainier?

II. Base Level
Define base level.

What is the difference in ultimate base level and a local(or temporary) base level?

Page 77- Bandon,Oregon
What is the base level of the Coquille River?

What is the base level of Bear Creek(D,4-E,5)?

Why does Bear Creek have so many more small meanders at E,5, while Randlemann Creek (E,5) is almost straight?

(over)

ACTIVITY 17.2: Stream and Stream-Related Features (continued)

II. Base Level (continued)
Page 107- Alma, Wisconsin/Minnesota
Relate the fact that Buffalo Creek(A,3-5) is very wide and swampy to the concept of base level.

What is the base level of the Mississippi River?

III. Stream Erosion
Name and explain the types of stream erosion.

Page 38- Lake McBride, Kansas
What kind of erosion is occurring on the steep, short valleys on this map?

What is going to happen to the upland areas because of this?

What kind of erosion is most common on the surface at C,2?

Page 57- Chief Mountain,Montana
What kind of erosion would you think is most common in the many creeks in this mountainous region?

Why?

A major feature created by stream erosion is the meander. Explain how meanders form.

(over)

ACTIVITY 17.2: Streams and Stream Related Features (continued)

III. Stream Erosion (continued)
How do meanders widen stream valleys. Explain and diagram!

Page 15- St. Paul,Arkansas
Why has the stream (River) at A,3;B,3;B,4;C,4 andC,5 started to meander, while most of the other streams in the area have not?

Page 36- Oolitic,Indiana
Notice the steep valley walls on the outside of the meanders along the White River. What kind of meanders are these? Oh-Oh, out of order!

How did they form?

Explain the origin of the valley now occupied by Crooked Creek(D,2).

Page 42- Campti, Louisana
Old River(B,1-2) is now a lake. Name the type of lake it is and explain its' origin.

Locate another section of the river where this process may soon create another lake.

(over)

ACTIVITY 17.2: Stream and Stream Related Features (continued)

IV. Stream Deposition and Valley Development
Explain why streams deposit their sediment load.

A common depositional feature is the floodplain. Explain how they form. Hint! Widen your valley first.

Page 13- Bright Angel,Arizona
Does the Colorado River have much of a floodplain?

How can you tell by looking at the map?

Explain the width(or lack of width) of the floodplain.

Page 42- Campti, Louisiana
This area is almost all floodplain. Explain why the floodplain is so wide. (A little geograhpy would help.)

There are several sediment (sand) bars on this map. Locate two(2) by grid, describe how they are shown, and explain their origin.

The floodplain has a variety of backswamps and natural levees. Explain how both features are formed.

natural levees-

backswamps-

ACTIVITY 17.2: Stream and Stream Related Features (continued)

IV. Stream Deposition and Valley Development (continued)

Page 22- Ventura,California

The central part of this map contains the Ventura River delta. Explain the origin of the delta and describe how it is shown on the map.

Even though little water is shown in the river, what indications are there that, at times, large volumes of water does flow onto the delta.

Page 58- Ennis,Montana

A large alluvial fan is shown on the map. Explain the origin of the fan.

V. Drainage Patterns

Provide the necessary information on the chart below.

MAP	DRAINAGE PATTERN	CONTROL OR CAUSE OF PATTERN DEVELOPMENT
p. 40 Hillsboro, Kentucky		
p. 12 Antelope Peak, Arizona		
p. 35 Effingham, Illinois		
p. 104 Mount Rainier, Washington		
p. 59 Ashby, Nebraska		
p. 16 Waldron, Arkansas		

(over)

ACTIVITY 17.2: Stream and Stream Related Features(continued)

VI. Types of Stream Valleys
Name the four types of stream valleys.

Page 44- Katadin,Maine
The stream valleys on the sides of Mt. Katahdin are of which type.

Explain your answer.

Page 16- Waldron,Arkansas
The drainage in this region follows the shape of the rock structure. What type of stream valleys are they?

Describe their origin.

Page 105- Yakima East,Washington
The deep canyon at A,2 represents an antecendent stream valley.(I know, because it states that at the bottom of the map.) Explain the origin of the valley.

Page 100- Strasburg,Virginia
The Applachians have many wind and water gaps. Several can be seen on this map.
Locate and name two(2) water gaps . Also explain their origin.

Locate and name one(1) wind gap. Of course; explain how it was created.

ACTIVITY 17.2: Stream and Stream Related Features (continued)

VII. Stream Valley Evolution
Look at the following maps and determine what stage of development the region shown,is in. List at least four characteristics that back up your decision.

Page 13- Bright Angel,Arizona

Page 15- St. Paul,Arkansas

Page 19- Mount Tom,California

Page 35- Effingham, Illinois

Page 42- Campti,Louisiana

Page 52- Jackson, Michigan

Page 56- Ironton,Missouri

Page 40- Hillsboro,Kentucky
This region is sais to be "rejuvenated". Explain what that means and how you can tell it has occurred here.

(over)

ACTIVITY 17.2: Stream and Stream Related Features (continued)

VIII. Streams and People

Observe the streams on the following maps. Try to determine how the streams and/or stream valleys might have influenced people relative to travel, settlement, and land use. Also note problems that may occur due to people using these areas.

Page 13- Bright Angel,Arizona

Page 22- Ventura,California

Page 24- Commerce City,Colorado

Page 38- Lake McBride,Kansas

Page 46- Cumberland,Maryland/West virginia

Page 70- Mount Mitchell,North Carolina

Page 81- Altoona,Pennsylvania

Page 107- Alma,Wisconsin/Minnesota

THE END! You probably have gray hair and are ready for retirement by now, but you sure know alot about streams.

Chapter 18

ACTIVITY 18.1: Glaciation Charts

Objective: To review glacial processes and products.

Materials: Writing instrument and Chapter 18 information.

Procedure: Fill in the following charts with the necessary information. (They will further aid you in your chapter review.)

1. Fill in the chart, indicating the differences between valley and continental glaciers.

FEATURE	VALLEY GLACIER	CONTINENTAL GLACIER
AMOUNT OF AREA COVERED		
CONTROLS ON THE DIRECTION OF FLOW		
PREDOMINANT MATERIALS ERODED		
KIND OF TOPOGRAPHY PRODUCED		
KIND OF DEPOSITS		
End moraine		
Ground moraine		
Lateral moraine		
Medial moraine		
Outwash plain		
Valley train		
Kettle		
Esker		
Kame		
Drumlin		

(over)

ACTIVITY 18.1: Glaciation Charts (continued)

2. Fill in the chart by describing the appearance and formation of various glacial erosion features.

EROSIONAL FEATURES	TOPOGRAPHIC DESCRIPTION	HOW FORMED
Horn		
Col		
Arete		
Cirque		
U-shaped valley		
Paternoster lakes		
Hanging valley		
Roche moutonnée		

ACTIVITY 18.1: Glaciation Charts (continued)

3. Fill in the chart by describing the appearance and formation of various glacial deposition features.

DEPOSITIONAL FEATURE	TOPOGRAPHIC DESCRIPTION	HOW FORMED
TILL DEPOSITS Ground moraine		
End moraine		
Drumlin		
GLACIOFLUVIAL DEPOSITS Esker		
Kame		
Kettle		
Outwash deposits Outwash plain		
Valley train		
WIND DEPOSITS Loess		

ACTIVITY 18.2: Glacial Features on Topographic Maps

Objectives: To identify glacial features on topographic maps. To review the origin of some of those features.

Materials: 100 Topographic Map book, location grid, some knowledge about glaciers,Activity 18.1, text or all of them.

Procedure: Using the 100 Map book, answer the questions asked. Some questions may relate to background information as well.

I. Mechanics of Glacial Development

Page 104- Mount Rainier,Washington
Give the approximate elevation of the snowline.

How did you determine this?

Look at Emmons Glacier(C4). At what elevation does it appear that the zone of accumulation ends and the zone ablation begin?

How can you tell?

What is the difference in the two zones?

Which side of Mount Rainier seems most favorable to glacial development?

Why?

II. Glacial Erosion

Explain how glaciers erode.

Page 57- Chief Mountain,Montana
Using your grid, locate three(3) cirques.

Describe how they appear on the map.

(over)

ACTIVITY 18.2: Glacial Features (continued)

II. Glacial Erosion (continued)

Explain how cirques form.

Using your grid,locate three(3) tarns and name them.

Explain how tarns form.

Name and locate two(2) cols.

Origin?

Name and locate two(2) horns (no cows or trumpets).

Origin?

Page 19- Mount Tom,California

Pine Creek Valley (top center) is a glaciated valley. How can you tell from looking at the map?

Locate and name,at least, four(4) other glacial features on this map.

The three small stream valleys that empty into Pine Creek Valley at B,3 are hanging valleys. What does that mean and how did they form?

ACTIVITY 18.2: Glacial Features (continued)

III. Glacial Depositional Features

What causes glaciers to deposit their sediment load?

What is a moraine?

Page 84- Kingston, Rhode Island

Locate the end moraine on the map. Describe its' appearance and explain how it was formed.

How does a ground moraine differ from an end moraine?

Where would you expect the ground moraine to be in this area?

What is the surface called to the south of the end moraine?

Explain its' origin.

The information at the bottom of the map explains that kettles and kames are present in the area. Explain what each is and what kind of appearance each would have on the map.

kettle:

kame:

(over)

ACTIVITY 18.2: Glacial Features (continued)

IV. Glaciers,Landforms and People

Page 52- Jackson,Michigan
What kind of problems might people encounter in this glaciated area?

Page 68- Ithaca,New York
What use is being made of the large delta at the entrance to the glacially carved lake at A,4-5?

Foresee any problems?

Page 71- Emerado, North Dakota
Explain the origin of this surface.

What do you imagine is the primary land use in this area?

Why?

Chapter 19

ACTIVITY 19.1: Wind Erosion Problems

Objective: To analyze hypothetical wind-related problems and to suggest possible solutions to these problems.

Materials: Writing instrument.

Procedure: Read the situations below, and answer the questions.

1. You live on the east side of Lake Michigan, an area covered with kilometers of dunes. Small evergreen trees were planted many years ago to stabilize the dunes. Drought conditions existed for two years, and a forest fire easily caught, destroying the trees. Give the problems that could occur without vegetation, and suggest possible solutions to these problems.

2. You inherit an Illinois farm. A drought is in its fifth year. The previous owner was a wonderful person but a poor farmer. He dug up all hedgerows, farming every possible centimeter of his land, leaving it susceptible to wind erosion. What would your approach be to this problem farm? Would you have animals or crops? Why?

3. You are far away from civilization, traveling on an old dirt road. The engine of your car stops and cannot be fixed. Walking for help, it becomes hours before you see another car. There! Coming toward you! Relief! Can you believe it? Zoom! Your relief flew past you, showering you with a gritty-tasting dust. No doubt, your question is: "Was that dust moved by saltation or suspension?" In order to make this road more comfortable for others, what would you do to eliminate the flying dust? Why?

ACTIVITY 19.2: Dune Formation

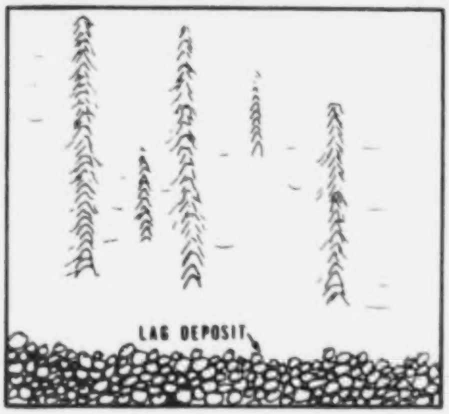
Objective: To determine dune types and formation.

Materials: Writing instrument.

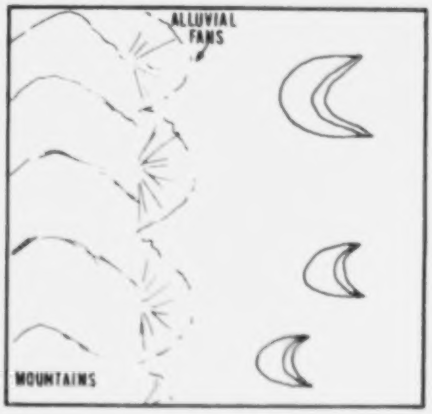
Procedure: Before solving many wind erosion problems, it is necessary to first determine the wind direction and the source of the sand. Observe the four aerial-view drawings below. For each of the drawings, do the following:

1. Name the type of dune.
2. Give the general wind direction.
3. Give the source of sand.
4. Discuss the controls influencing the development of the dune.

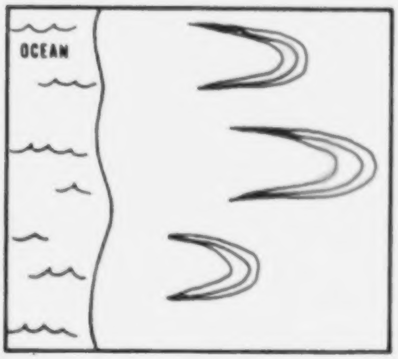
A



B



C



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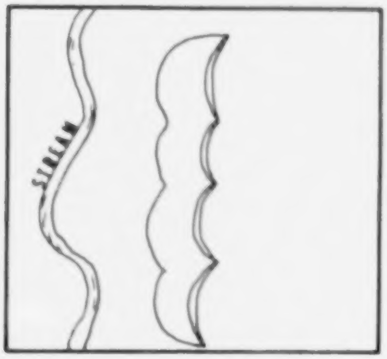


ACTIVITY 20.1: Wave Action on Topographic Maps

Objective: To identify wave processes and products on topographic maps.

Materials: 100 Topographic Maps and writing instrument.

Procedure: Turn to the indicated pages in 100 Topographic Maps, and answer the following questions.

1. p. 20: Point Reyes, California
   a) Explain the formation of Limantour Spit (D4,5).

   b) Would Drakes Bay be a good harbor? Why?

   c) What kind of erosional feature is Chimney Rock (E3)?

   d) Where is most erosion occurring along this shoreline?

   e) What is causing Drakes Estero (C3) to fill with sediment?

2. p. 21: San Luis Rey, California
   Locate the baymouth bar. What other feature has it created? How?

3. p. 22: Ventura, California
   What process besides wave action has helped create the beach in this area? How?

4. p. 43: South Pass, Louisiana
   Why are there land boundary lines where there is no land, and why is there land without numbers?

   What does this tell about the shoreline in the area?

(over)

ACTIVITY 20.1: Wave Action on Topographic Maps (continued)

5. p. 45: Mount Desert, Maine
   a) What evidence do you see that the area has a drowned shoreline?

   b) If sea level dropped a few meters, what would the feature connected to Moose Island (D1) be called?

6. p. 48: Lynn, Massachusetts
   a) Locate and name two (2) features formed by wave erosion.

   b) Locate and name two (2) features formed by wave deposition.

7. p. 51: Fennville, Michigan
   a) What is the purpose of the structure at the mouth of the Kalamazoo River (B1)?

   b) What indications are there that Lake Michigan was once deeper than it is now?

Chapter 20

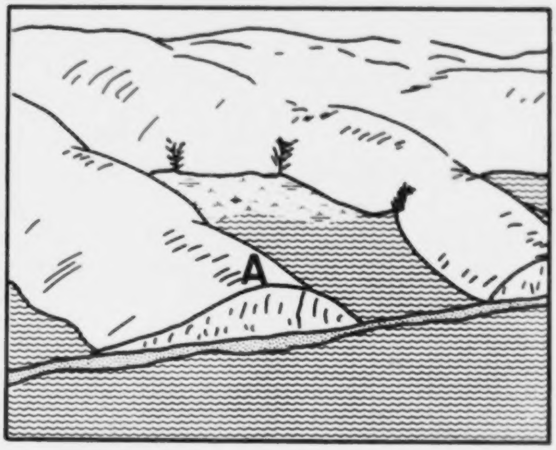
ACTIVITY 20.2: Wave Action Problems

Objective: To identify wave action problems, and to determine solutions to these problems.

Materials: Writing instrument.

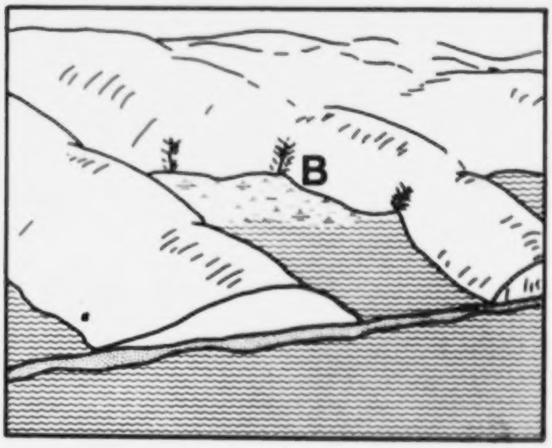
Procedure: Because of your previous success as a geologist, you have once more been asked to come to the rescue of some people who need your advice. Answer the questions below.

1. The Oceanview Estates (A) face several problems as a result of shoreline processes. What are they? Suggest some solutions.



A is Oceanview Estates

2. Since there were problems from erosion, Oceanview lots are now being sold instead at Shoreline Drive (B). What possible problems could occur for these homeowners?

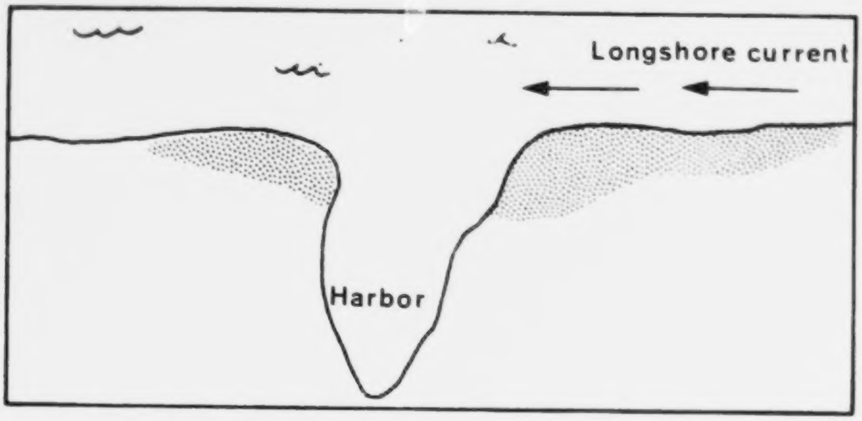


B is Shoreline Drive

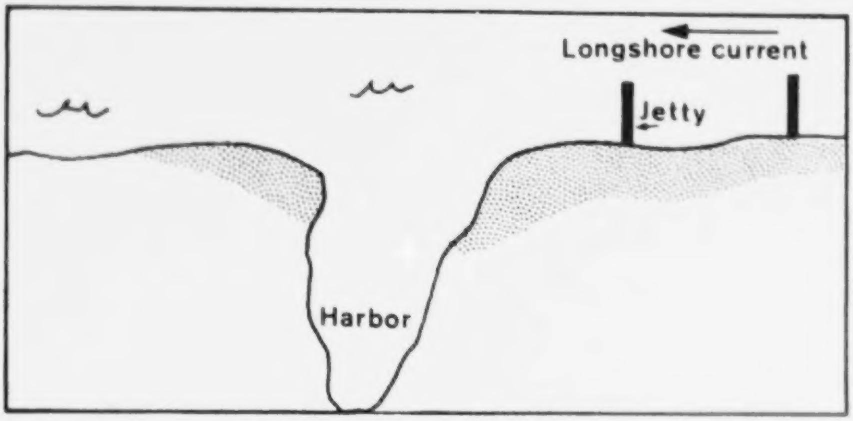
(over)

ACTIVITY 20.2: Wave Action Problems (continued)

3. Noting various locations on this shoreline, list possible effects longshore currents could have on the beach and the harbor.


Longshore current
Harbor

To control deposition across the harbor, jetties were built. What effect would they have on the beach and harbor?


Longshore current
Jetty
Harbor

ACTIVITY 20.2: Wave Action Problems (continued)

4. What considerations must be taken into account in forecasting the movement of this oil spill, and how much shoreline will be affected?